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IMPLICATIONS OF DRY GRASSLAND MANAGEMENT IN THE ECOLOGY AND CONSERVATION OF GRASSLAND BIRDS IN SOUTH PORTUGAL

Memoria presentada por **Nuno Rafael Rebelo Faria** para optar al Grado de Doctor en Ecología por la Universidad Autónoma de Madrid

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INDEX

I.INDEX OF FIGURES

II. INDEX OF TABLES

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VI. RESUMEN

En los sistemas herbáceos secos ibero-mediterráneos, el pastoreo por ganado y las siegas de heno son actividades agrícolas importantes que influyen con la ecología de las aves. Varias especies de aves utilizan estos hábitats y actualmente están experimentando un descenso casi continuo en sus poblaciones. En esta tesis, se ha evaluado el impacto de las siegas de heno y del manejo del pastoreo por ganado en una comunidad de aves de sistemas herbáceos secos de la región de Alentejo (sur de Portugal). Los trabajos se han centrado en los efectos de la intensidad y fechas de estas prácticas directamente sobre los parámetros poblacionales y de nidificación, e indirectamente en las características del paisaje y del microhábitat, como la estructura de la vegetación y la composición especifica de plantas y artrópodos como recursos tróficos. Como modelo de estudio para abordar estos problemas se ha utilizado, bien el sisón común (Tetrax tetrax) como especie de referencia, bien toda la comunidad de aves propias de los sistemas herbáceos.

Los principales objetivos de esta tesis fueron: (1) investigar las variaciones en la abundancia de aves y de la riqueza de especies en los campos, con respecto a las siegas de heno que ocurrieron en los años anteriores en esos campos y en su entorno; (2) investigar los cambios en la abundancia de aves y en la riqueza de especies, así como los potenciales movimientos de las aves que resultan del corte heno en un campo y su entorno en un determinado año; (3) investigar el microhábitat del sisón durante la época de nidificación y de cría de pollos, específicamente las relaciones entre la vegetación preferida (composición de plantas) y la abundancia de artrópodos; (4) investigar las respuestas de machos territoriales y hembras del sisón a diferentes componentes del manejo de ganado (tipo de pasto, carga animal y estructura de la vegetación); (5) investigar la exposición de diferentes especies al corte del heno; revelando eventual remoción de los nidos o mortalidad causada por la maquinaria; (6) relacionar la destrucción de nidos y la mortalidad de aves con las prácticas de gestión de heno.

Los métodos de campo incluyeran transectos en coche, transectos a pie y puntos de conteo para obtener los sitios de ocurrencia de sisón (2003 a 2006) o estimaciones de la abundancia de aves (2012 a 2015). Los métodos estadísticos utilizados fueron de tipo univariante y multivariante, basados en modelación lineal,

aditiva o mixta (GLM, GAM y GLMM). La selección de modelos se ha realizado a través del uso del AICc (Akaike's Information Criteria) y de modelos promediados.

Los resultados indican que la abundancia de aves en un campo está positivamente relacionada con la superficie cortada en el entorno de ese campo en el año anterior. Sin embargo, se encontraron efectos anuales contrastantes para los no paseriformes. Algunas especies prefieren campos con menos cortes de heno o superficie cortada (por ejemplo, la cogujada montesina), mientras que otras prefieren campos gestionados con frecuencia para la producción de heno (por ejemplo, la cogujada comun y el triguero). La siega del heno induce el abandono de los campos y conduce a un fuerte descenso en la abundancia de aves en los campos. Los modelos obtenidos para sisón indican que la especie se encuentra principalmente en los sitios con alta riqueza florística y gran abundancia de especies de Fabaceae, aunque la composición vegetal difiere entre las áreas de machos y hembras. Se reveló que estas variables son cruciales para proporcionar mayores abundancias de artrópodos, en especial de Acrididea, Formicidae y algunos grupos de coleópteros que son decisivos para la selección de los sitios de parada y de reproducción de las hembras. Por otro lado, los sisones se encuentran principalmente en los pastos de largo plazo y con pastoreo bajo a moderado. Por el contrario, se encontró una menor probabilidad de ocurrencia en los campos con altas cargas de pastoreo o sin pastoreo. Los transectos en campos segados para heno revelaron un bajo número de intentos de anidación con éxito, lo que sugiere una alta eliminación de nidos/aves muertas por la maquinaria. Las probabilidades más altas de eventos de mortalidad se encontraron en los campos segados mas tarde (pero no en todos los años) y con rastrillos hileradores de un rotor.

Se concluye que los efectos intra-anuales de las siegas de heno tienen un mayor impacto en las aves de sistemas herbáceos que los efectos interanuales. El mantenimiento de las siegas de heno en niveles bajos, a través de la rotación anual de las siegas por los distintos campos de las fincas y el uso de cortes parciales, puede ser una forma adecuada para asegurar una gestión efectiva de las poblaciones de aves de sistemas herbáceos. Por otra parte, el retraso en la siega del heno, el ensilaje utilizando cultivos temporales, producir rastrojos altos y el desarrollo de nuevas soluciones tecnológicas para la siega del heno se han señalado y discutido como alternativas de gestión. Este trabajo demostró la utilidad del sisón como especie indicadora del buen estado de gestión/conservación de los sistemas hebáceos de secano para el seguimiento de los cambios en los hábitats y los procesos de intensificación en curso en dichos sistemas. Finalmente, esta tesis ha puesto de relieve la importancia de la riqueza y de la composición florística en la disponibilidad

de recursos tróficos para la especie, así como la conveniencia de mantener pastos de largo plazo más extensos y cargas ganaderas de bajas a moderadas en los planes de gestión de las aves de sistemas herbáceos.

VII. ABSTRACT

In Iberian Mediterranean dry grasslands, grazing by domestic animals and haying are important agricultural activities influencing bird ecology. Several bird species typical of these habitats are now experiencing a nearly continuous population decline. In this thesis, I evaluated the impact of haying and livestock grazing management on a Mediterranean dry grassland bird community of Alentejo region (south Portugal). I focused on the effects of intensity and timing of these practices, directly on population and nesting parameters and indirectly on landscape and microhabitat features, such as vegetation structure, plant composition or food resources (arthropods), either using the little bustard as an indicator, species or the whole grassland bird community.

The main objectives of this thesis were: (1) to investigate variations on bird abundance and species richness in the fields, with respect to past haying events occurred in a field and its surroundings; (2) to investigate the shifts on bird abundance, species richness and potential between-field bird movements resulting from haying a field and its surrounding area in a given year; (3) investigate microhabitat selection by little bustards during the nesting and chick-rearing season, focusing on the relationships between preferred vegetation (plant composition) and arthropod abundance; (4) to investigate responses of little bustard territorial males and breeding females to different livestock management components, namely pasture types, stocking rates and sward structure; (5) to investigate the exposure of different species to haying; revealing potential removal of nests or dead birds by haying machinery; (6) to link clutch destruction and bird mortality with haying management practices.

Field methods included car transects, foot transects and point counts to gather bird information on the occurrence sites of the little bustard (from 2003 to 2006) or estimates of bird abundance (from 2012 and 2015). Statistical methods consisted in univariate and multivariate approaches, based on linear, additive or mixed modelling (GLM, GAM and GLMM). The Akaike's Information Criteria (AICc) and model averaging were use for model selection.

Results indicate that bird abundance in a field is positively related with the surface hayed in the vicinity of that field in the previous year. However, contrasting yearly effects were found for non-passerines. Also, some species prefer fields with less haying events or surface hayed (e.g. the Thekla lark), whereas others occur mostly in

fields frequently managed for haying (e.g. the crested lark and corn bunting). Haying a field induces the abandonment of a field, leading to a strong decline on bird abundance. The models obtained for little bustard indicates that the species occurs mostly in sites with high floristic richness and high abundance of Fabaceae species, although plant composition differs from male to female sites. These variables were found to be crucial to provide higher abundances of arthropods, notably of Acrididea, Formicidae and some groups of Coleoptera which are decisive for the selection of displaying or female breeding sites. On the other hand, little bustards were mostly found in long-term pastures and under light-moderate grazing conditions (stocking rates around 0.4 LU/ha). Conversely, lower probabilities of occurrence were found in ungrazed or heavy grazed fields. The transects on hayed fields revealed a low number of successful nesting attempts, suggesting a high nest/dead bird removal by the machinery. Higher probabilities of mortality events were found in fields mown earlier (but not in all years) and raked with one-rotor rotary rakes.

I conclude that intra-annual effects of haying have higher impact on grassland birds than the inter-annual effects. Maintaining haying at low levels, by rotating haying yearly through the different fields of each farm and using partial haying, may be an adequate way to ensure an effective management of grassland bird populations. Furthermore, delayed haying, silage using temporary crops, leaving taller stubbles and the development of new technological solutions for haying are pointed out and discussed as management alternatives. These works revealed the usefulness of the little bustard as indicator species to track changes in habitats and the ongoing intensification processes in dry grassland environments, by highlighting the importance of plant richness and composition in providing food resources for the species and the importance of the maintenance of the larger long-term pastures and low to moderate stocking rates in management plans of grassland birds.

1. GENERAL INTRODUCTION

1.1. Grasslands in European, Iberian and Alentejo landscapes: definition, origin and range

Grasslands are ecologically defined as herbaceous vegetation types that are mostly dominated by grasses (Poaceae) or other graminoids (Cyperaceae, Juncaceae) and have a relatively dense vegetation cover (usually > 25%), thus excluding plant communities mostly composed of shrubs of varying height (shrublands), bryophytes and lichens as well as those with very scattered vegetation (e.g. deserts, semi-deserts, screes; Janisová et al. 2011). From the Egeo-Anatolian area, westwards all across the Mediterranean regions but especially in the Iberian Peninsula, clusters of extrazonal enclaves or relicts of primary grasslands occur (Bredenkamp et al. 2002). However, unlike the steppe of central Asia and of the Pontic region in Europe, the dry grasslands of Western Europe are mostly secondary and anthropogenic (Suárez et al. 1991). Their origin and maintenance are mostly linked to forest clearing and subsequent low-intensity agricultural management such as cultivation, mowing, grazing by domestic livestock and even fire (Coupland 1979, Pott 1995, Suárez, et al. 1991). The clusters of primary grassland were gradually enlarged by the herds of the first domestic grazers of the early Neolithic in the Middle East (Pott 1995) and in some cases might have merged with secondary grassland to form the contemporaneous grasslands of western Europe and served as a reservoir of species for colonization of the newly formed human made open spaces in the place of former forest (Bredenkamp et al. 2002).

Nowadays, European grasslands are increasingly transformed into improved (intensive) grasslands by artificial fertilization, increased mowing frequency or stocking rates and frequent re-sowing with a limited set of agronomically valuable species (Hejcman et al. 2013, Peach et al 2013, Stevens et al. 2010). The definition of grassland needed therefore to be reformulated from an agronomical perspective. Peeters et al. (2013) defined grasslands as land devoted to the production of forage for harvest by grazing/browsing, cutting, or both, or used for other agricultural purposes such as renewable energy production. The vegetation can include grasses, grass-like plants, legumes and other forbs, and woody species may also be present. Grasslands can be classified as permanent or temporary (Peeters et al. 2013). Permanent grasslands are those used to grow grasses or other forage (self-seeded or sown and/or reseeded) that have not been completely renewed after destruction by ploughing or spraying (herbicide) for ten years or longer. They can be agriculturally improved, semi-natural, natural or no longer used for production. Temporary grasslands are sown with forage species that can be annual, biennial or perennial. They are sown on arable land and can be integrated in crop rotations or sown after another grassland vegetation. They are kept for a short period of time, from a couple of months to (usually) a few years. They can be established with pure sowings of legumes, pure sowings of grasses or grass-legume mixtures.

After having been significantly reduced in the last 30 years, European grasslands occupy presently about 39% of the total utilized agricultural area (UAA; Huyghe et al. 2014). In Portugal, grasslands are mostly distributed south of Tagus River, particularly in Alentejo region. Contrasting with other European

countries, the occupation of permanent grasslands showed a considerable increase since 1989, representing in 2009 about 50% of the utilized agricultural area in Portugal and 59% in the Alentejo region (Fig. 1; INE 2015a). On the contrary, temporary grasslands have been reduced in Portugal since 1989, but not in Alentejo region showing an increase of 10% in the same period (Fig. 1).

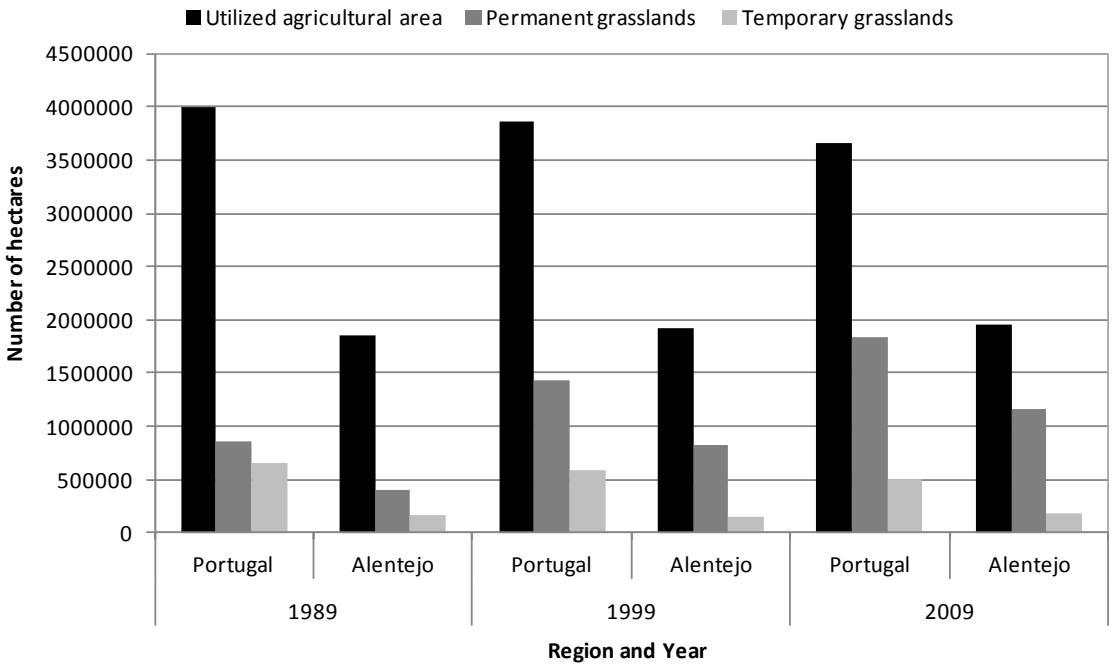

Fig. 1 - Trends of grassland extent in Portugal and Alentejo region for the 1989-2009 period. The utilized agricultural area, permanent and temporary grasslands are presented (Source: INE 2015a).

1.2. Grazing and haying as drivers of ecological processes in grassland systems: the effects on birds

Currently grazing systems cover more than 25% of the surface of the globe (Fig. 2), having increased their footprint over 600% in the last three centuries, occupying a geographic area larger than any other form of land use and contributing to the overall process of desertification, deforestation and modification of plant communities of various terrestrial biomes (Asner et al. 2004). The ecological impacts of grazing are reflected both in the diversity of vegetation and species richness, through modulation (accelerating or decreasing) the nutrient cycling, primary production, natural succession and abiotic disturbance (Hobbs 1996).

Grazing is an integral part of the dynamics of Iberian agricultural landscapes, interacting with the rural environment both socially and economically, and contributing over time to the equilibrium of ecosystems. Dry grasslands were during centuries predominantly used for sheep rearing in complement with extensive cereal production (see Correal at al. 2006 for an extensive view on this subject). However, in recent years, strong changes occurred in livestock populations across Europe. Most of these changes directly or indirectly resulted from the Common Agricultural Policy (CAP) implemented since 1962 in the countries of the European Union (Donald et al. 2002). The main goals of CAP, defined in Article 39 of the Treaty on the Functioning of the European Union, are as follows:

- To increase productivity, by promoting technical progress and ensuring the optimum use of the factors of production.
- To ensure a fair standard of living for the agricultural community.
- To stabilise markets.
- To secure availability of supplies.
- To provide consumers with food at reasonable prices.

The homogeneous implementation of CAP throughout the EU resulted in simplification and standardization of processes at field, landscape and regional levels, due to the abandonment of economically marginal uses and mixed production systems (Evans 1997). Concerning livestock trends, while dairy cow numbers strongly declined in the EU between 1975 and 2007, the remaining types of cattle (mostly suckling cows) showed an opposite trend. This was mostly due to an increase in cattle numbers on specialists beef cattle farms but also due to the conversion of dairy cattle farms in beef cattle farms (Huyghe 2014). In Alentejo region, bovine numbers experienced an increase of 106% between 1989 and 2013 (INE 2014a). Also, between 1999 and 2013, in the neighbour areas of southwest Spain (Extremadura and Andalucía regions), bovine numbers increased by 11%, (INE 2014b, MAGRAMA, 2014).

On the other hand, despite having significantly increased in most European countries (Huyghe 2014), sheep numbers decreased by about 39% in Alentejo region (INE, 2014a). Also, between 1999 and 2013, in southwest Spain (Extremadura and Andalucía regions), sheep numbers decreased by 13%, (INE 2014b, MAGRAMA 2014).

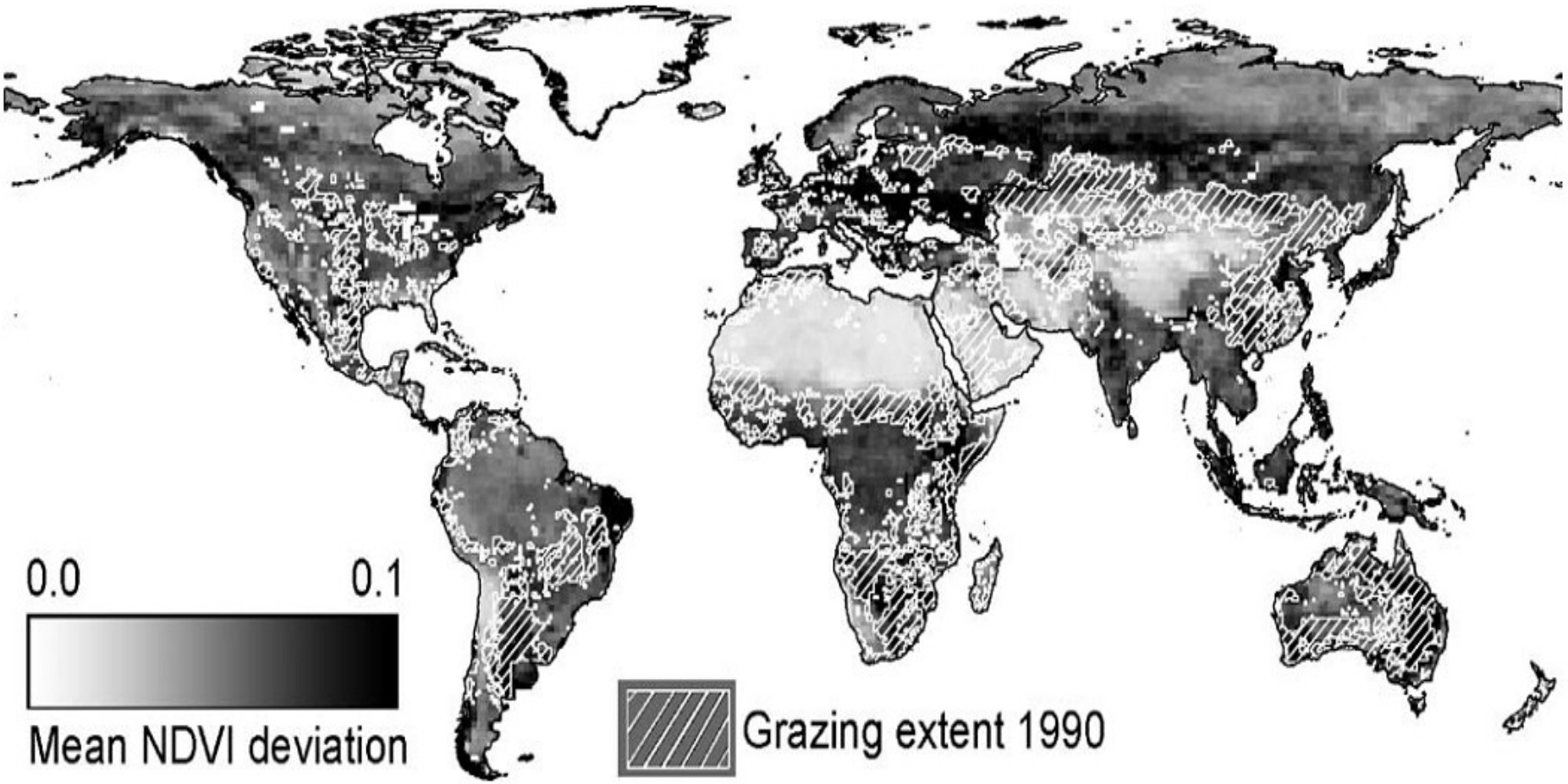

Fig. 2 - Global extent of grazing systems in 1990 (Source: Asner et al. 2004).

In the last years, mowing for hay (haying or haymaking) or silage production became increasingly used in Iberian dry grasslands providing a feeding alternative in periods where grassland biomass production in farms is insufficient to ensure livestock feeding needs, or when animal products are obtained from stabled livestock. In the Iberian dry grasslands haying occurs both on cereal/legume forage crops and on semi-natural spontaneous dry grasslands. There are no official statistics on the area mown yearly for hay or silage production in Portugal (or other parts of southwest Iberia) but these numbers are expected to be correlated with the area of permanent grasslands, bovine numbers and the area of temporary crops. In Portugal, the surface of the main temporary crops used for haying (forage oats, grass-legume crops or pure legume crops) increased by 34% between 1989 and 2009 (INE 2014a). In southwest Spain (Extremadura and Andalucía regions), between 1999 and 2013 the surface of forage crops experienced a 65% increase (INE 2014b, MAGRAMA 2014).

Unlike grazing, mowing is non-selective, so sward heterogeneity is greatly reduced and the removal of grass also reduces the amount of organic matter returned to the soil (Vickery et al. 2001). Indeed, contrasting results were found between studies in temperate regions focusing on the effects of mowing and grazing on plant diversity (Turtureanu et al. 2014, Stammel et al. 2003, Socher et al. 2012).

The effects of grazing on grassland birds can be direct through trampling, disturbance of breeding sites, or trophic competition; and indirect by modifying the structure of vegetation, soil parameters or the dynamics of plant communities (see Prior 2011). Indirect operational impacts are also described in

literature usually resulting from the construction of building structures for livestock (eg. fences) and the use of external insecticides in cattle (Henny et al. 1995, Mineau et al. 1999). The abandonment of grazing may also contribute to declines on grassland bird populations due to the changes induced by natural succession on vegetation structure (Suárez-Seoane et al. 2002, Sirami et al. 2008). In the Iberian Peninsula, grazing abandonment is mostly associated to mountain areas but local effects can also be found in dry grassland systems (see Regos et al. 2014 and Suárez-Seoane et al. 2002, for examples). On the other hand, links between hay management and changes in avian populations have rarely been established, particularly in Mediterranean landscapes (see Perlut et al. 2006, for an example in a temperate region). It is well known that mowing machinery and mowing timings are likely to put grassland bird population at risk by causing reproductive failure through loss of nests and eggs, chick mortality or adult mortality (Gruebler et al. 2008, Vickery et al. 2001). Also, the management of the amount of inputs and number of cuttings may be responsible directly or indirectly for the high spatial variability on arthropod abundance at the landscape scale (Badenhausser et al. 2009, Chambers and Samways 1998). This variation is expected to have an effect on grassland birds since arthropods are an important food resource for them (see Jiguet 2002, Rocha et al. 2005).

1.3. The Iberian dry grasslands as habitat for birds: avifaunal diversity, trends and conservation issues

European agricultural habitats have the highest overall bird species richness of any habitat (Tucker 1997). As stated behind, Iberian grasslands

resulted from a long-term coexistence with livestock, which favoured high levels of functional and structural plant diversity (Ollero 2013). Ribeiro et al. (2014) showed that in Iberian dry grasslands slight extensive grazing by sheep maximizes diversity and can contribute to both maintenance of species diversity and to the increase in legume cover. These are certainly key factors underlying the high levels of bird diversity also found in Iberian dry grasslands, notably of threatened grassland or steppe bird species, such as the great bustard (*Otis tarda*), the little bustard (*Tetrax tetrax*), the black-bellied sandgrouse (*Pterocles orientalis*) or the southern grey shrike (*Lanius meridionalis*). It must be acknowledged that the definition of dry grassland birds in the Iberian context mostly overlaps with the definition of steppe birds (De Juana 2005). Steppe birds are those inhabiting steppe like habitats, that recreate natural steppes of Central Asia also called “pseudosteppes” (Suarez et al. 1997). Pseudostepes (and Iberian dry grasslands in general) are characterized by flat relief, grass dominated (treeless) plant cover and extensively cultivated landscapes. Santos and Suárez (2005), point out the Iberian Peninsula as the most important region for steppe birds in the European Union since 1) all of the UE steppe birds exist in Iberia and 2) some of these species occur exclusively or quasi-exclusively in Iberia within the EU. Therefore, the conservation of grassland habitats within this region is vital in order to maintain the viability of the grassland bird populations in Europe.

Biodiversity loss has accelerated over the past two centuries all over the world, as a direct or indirect result of human growth, unsustainable consumption patterns and environmental changes (RSPB 2003). Grassland birds are often used as bioindicators of agri-pastoral habitats (Brotons et al.

2004, Suárez et al. 1997). Their conspicuity, diversity and the three dimensional use of space, allow a rapid detection of responses to changes in habitat. Together with the increase in the irrigated surface and agrochemicals use (see Brotons et al. 2004 and; Guerrero et al. 2010), the changes in grazing and haying management, shown by the statistics on grassland management over the last decades presented above are likely to be reflected in the recent trends of grassland bird populations in Iberia. According to Morales et al. (2013), grassland specialists in Spain decreased by about 15% from 1998 to 2011. The decrease was similar if we consider all the birds associated to agricultural landscapes (Seo/BirdLife 2012). The little bustard, for instance, decreased by 37% but a decrease of 75 % between 1998 and 2008 was found in other studies in Extremadura region (De Juana, 2009). The calandra lark (*Melancorypha calandra*) decreased by 26% and the tawny pipit (*Anthus campestris*) by about 41% (Seo/BirdLife 2012. These results contrast with the trends of forest birds which increased by about 12% in the same period. At European scale, species like the corn bunting decreased about by 61% between 1980 and 2010, whereas the little bustard and the calandra lark decreased by 41% and 34% respectively (PECBMS 2015). These numbers are particularly alarming because the populations of these species are mostly concentred in Europe. Such declines are reflected in the present conservation status of grassland bird species. Currently, about 23% of the dry grassland species breeding in the Iberian Peninsula are listed in the European or Global Red Lists of birds (Table 1).

Table 1 - World and European Red List status of breeding Iberian dry grassland species (compiled from IUCN 2015 and BirdLife Internacional 2015; LC – Least concern, NT – Near-threatened, VU - Vulnerable).

Species	Red list status	
	World (IUCN)	**Europe (BirdLife International)**
Montagu´s harrier *Circus pygargus*	LC	LC
Black-shouldered kite *Elanus caeruleus*	LC	LC
Lesser kestrel *Falco naumanni*	LC	LC
Common kestrel *Falco tinnunculus*	LC	LC
Red partridge *Alectoris rufa*	LC	LC
European quail *Coturnix coturnix*	LC	LC
Little bustard *Tetrax tetrax*	**NT**	**VU**
Great bustard *Otis tarda*	**VU**	LC
Eurasian stone-curlew *Burhinus oedicnemus*	LC	LC
Black-bellied sandgrouse *Pterocles orientalis*	LC	**VU**
Pin-tailed sandgrouse *Pterocles alchata*	LC	LC
European roller *Coracias garrulus*	**NT**	LC
Calandra lark *Melanocorypha calandra*	LC	LC
Skylark *Alauda arvensis*	LC	LC
Short-toed lark *Calandrella brachydactyla*	LC	LC
Crested lark *Galerida cristata*	LC	LC
Thekla lark *Galerida theklae*	LC	LC
Tawny pipit *Anthus campestris*	LC	LC
Black-eared wheatear *Oenanthe hispanica*	LC	LC
Zitting cisticole *Cisticola juncidis*	LC	LC
Southern grey shrike *Lanius meridionalis*	LC	**VU**
Corn bunting *Emberiza calandra*	LC	LC

In counter-cycle with the trend for intensification of agricultural habitats, agri-environment schemes have been applied all over the European Union in the last years, with the aim of halting the decline of steppe birds, notably in the Alentejo region (Leitão 2007, Moreira et al. 2005). These frequently included specific measures for controlling the effects of grazing intensification or abandonment. In spite of the relevance of Iberian steppe bird populations in

global steppe conservation, studies are still providing information on the mechanisms underlying bird sensitivity to grazing or haying are still incipient. This situation hampers the development of robust sustainability indicators to measure and validate the effectiveness of these measures.

1.4. Context and objectives of the thesis

1.4.1. Context of the thesis

Contrasting with arable farmland, the information on grassland habitat use by birds in the Mediterranean context is scarce (but see for instance, Fonderflick et al. 2010, Reino 2009). For the little bustard in particular, there is already a considerable amount of information available from French populations (Wolff 2001). However, French Mediterranean grasslands are quite different from those found in the Iberian Peninsula (Wolff 2005). In Portugal, the existing knowledge on the effects of livestock management on grassland birds stems mostly from the Castro Verde Zonal Plan (Borralho et al. 1999, Domingos 2008, Oréade-Brèche 2005), where promising results have been obtained for the little bustard and for steppe birds in general. However, scientific information concerning the mechanisms by which the applied livestock agri-environmental measures operate was simply missed.

Aiming to fill to this information gap, two projects focusing on the ecology of the little bustard in Alentejo region were financed between 2003 and 2006, by the Coordination Commission of the Alentejo Region (Portugal):

Pr1. Estudo da Bio-ecologia do Sisão (Tetrax tetrax) em Período de Reprodução no Sítio de Interesse Comunitário da Cabrela.

Pr2. Estudo da Bio-ecologia do Sisão (Tetrax tetrax) em Período de Reprodução no Sítio de Interesse Comunitário da Cabrela (2ª Fase).

The information of this thesis partly originates from the outputs of these projects (Chapters 3 and 4). The remaining information of this thesis (chapters 2 and 5) was obtained during the works supported by the grant SFRH/BD/74840/2010 funded by the Portuguese Science and Technology Foundation (FCT- Fundação para a Ciência e Tecnologia). The information collected within this grant allowed broadening the object of study, both geographically and in the scope of knowledge, ensuring research on the whole grassland bird community.

1.4.2. Study areas

Two areas were selected in Alentejo Region (South Portugal): the Évora plains, that partly include the Special Protection Area (SPA) of Évora; and the Important bird and biodiversity area (IBA) of Cabrela (Fig. 3). The study area of Évora (7.884902W, 38.533521N) is within in the Mesomediterranean biogeographic region (Rivas-Martinez et al. 2004). Climate is mostly dry, although more humid at North and West quadrants. Average annual rainfall rounds 586mm (1981-2010 period; IPMA 2015). This area comprises a mosaic landscape dominated by holm oak (*Q. rotundifolia* Lam.) forested areas

'montados' and grasslands. Soils are mostly acidic and with low-average fertility (own unpublished data).

The study area of Cabrela (8.333366W, 38.483349N) is located in the Mesomediterranean and Thermomediterranean biogeographic regions (Rivas-Martinez et al. 2004). Climate shows both ocean and continental influences, shifting from sub-humid to dry and the average annual rainfall varies between 574 and 708 mm (SNIRH 2007). The study area is part of a mosaic landscape dominated by *Quercus suber* (L.) and/or *Q. rotundifolia* (Lam.) forested areas, grasslands and river valleys. Soils are mostly acidic and with diverse levels of fertility (IA 1980, IDRhA 1982).

In both areas the most important land uses are livestock grazing (mostly cattle) and, in a lesser extent, cereal crops for grain or hay production.

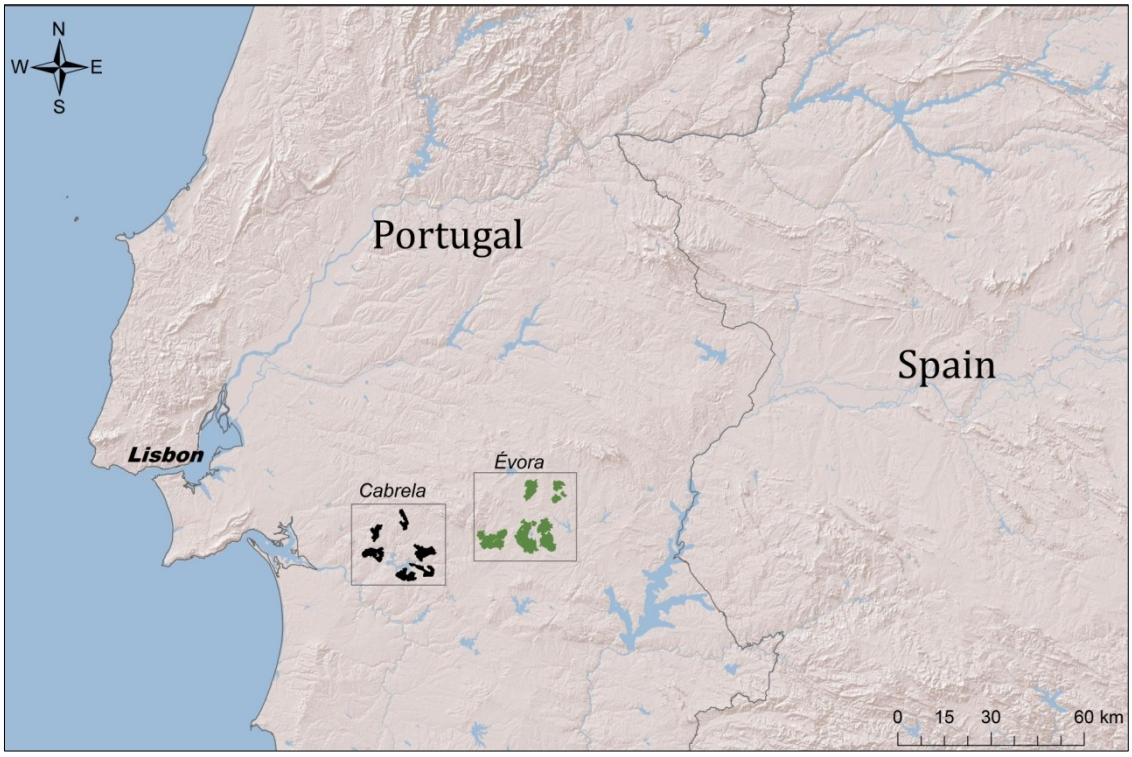

Fig. 3 - Geographical location of the study areas of Cabrela and Évora.

1.4.3. Objectives and structure of the thesis

The general objective of this thesis is to establish ecological relationships at field and landscape scale during the breeding season between dry grassland birds and livestock management practices in the grasslands of Alentejo region (Portugal), making particular emphasis on the ecology of the little bustard, as well as to suggest management options compatible with maintenance of grassland bird populations. Within this framework, this thesis focuses on two major subjects, haying and livestock grazing, in accordance with the specific objectives (SO) listed below:

SO1. To investigate the inter-annual and intra-annual effects of haying on dry grassland bird population spatial dynamics. My hypotheses are: (1) past haying events occurred in a field and in the surroundings of a field (number, surface and year of last haying) influence bird abundance and species richness; (2) haying a field and the surrounding area alters the spatial dynamics of grassland birds resulting in immediate between-field shifts on bird abundance and species richness.

My expected outputs were to present adequate measures to conciliate haying practices and the conservation of Mediterranean grassland bird communities at landscape scale. The research carried out concerning this specific objective was fully developed in Chapter 2 in the manuscript entitled:

Inter-annual and intra-annual effects of haying on grassland bird populations and spatial dynamics. (Submitted to Agriculture, Ecosystems and Environment).

SO2. To investigate the relationships between plant species diversity and composition in grassland habitats with arthropod abundance and richness, and to assess how these relationships influence grassland use by birds, using the little bustard as a study case. My hypotheses were: (1) Plant composition influences microhabitat selection by the little bustard and sexual segregation may occur based on the plant communities found at breeding sites and; (2) vegetation typologies are relevant in providing food resources (arthropods) for the species and particularly for growing juveniles.

My expected outputs were (1) to identify the plant species that can be most valuable for pasture improvement-restoration and those which should be avoided in management actions aimed at bird conservation and; (2) to define guidelines for the management of Mediterranean extensive pastures in order to maintain their suitability as breeding habitat for little bustards and other steppe birds. The research carried out concerning this specific objective was fully developed in Chapter 3 in the manuscript entitled:

Linking plant composition and arthropod abundance to establish little bustard breeding requirements in pastureland dominated landscapes (Published in Biodiversity and Conservation, 2012, Vol. 21, Issue 8, pages 2109-2125).

SO3: To investigate grassland use by birds in areas with dominance of pastureland using the little bustard as case study, evaluating the importance of grazing in shaping suitable swards for both sexes of the species. My hypotheses are: (1) livestock handling practices and pasture characteristics influence the selection of breeding grounds; (2) the stocking rates modulate sward structure affecting the spatial distribution of territorial males and breeding females, during the nesting and chick-rearing periods.

My expected outputs were to (1) to define optimum stocking practices for the management of little bustard breeding populations and; (2) to suggest ecological stocking practices for an integrated conservation of steppe bird communities. The research carried out concerning this specific objective was fully developed in Chapter 4 in the manuscript entitled:

> **The importance of grazing regime in the provision of breeding habitat for grassland birds: the case of the endangered little bustard (*Tetrax tetrax*)** (Published in Journal for Nature Conservation Vol. 20, Issue 4, 2012, pages 211–218.)

SO4. To assess the effects of hay production on a ground nesting bird community using observations directly obtained at nesting sites after haying field works. My main objectives were (1) to investigate the exposure of different grassland species to haying practices; (2) to investigate the removal of nests or dead birds in mown fields, assessing the roles of type of machinery and sward properties, as well the potential biases on the detectability of records; (3) to analyze the influence of mowing machinery configuration, type of field (grazed,

ungrazed, seeded) and the timing of mowing/baling on clutch destruction and bird mortality.

My expected outputs were to present measures for haying management that may minimize nest destruction and mortality in hayed fields. The research carried out concerning this specific objective was fully developed in Chapter 5 in the manuscript entitled:

Exploring nest destruction and bird mortality in mown Mediterranean dry grasslands: an increasing threat to grassland bird conservation. (Submitted to Grass and Forage Science).

2. INTER-ANNUAL AND INTRA-ANNUAL EFFECTS OF HAYING ON GRASSLAND BIRD POPULATIONS AND SPATIAL DYNAMICS

ABSTRACT

We evaluate the inter-annual and intra-annual effects of haying on grassland birds in Alentejo region, Portugal. Our main goals were: (1) to investigate variations on bird abundance and species richness in the fields, with respect to past haying events occurred in a field and in the surroundings of a field and; (2) to investigate the shifts on bird abundance and species richness and potential between-field movements by birds resulting from haying a field and the surrounding area in a given year. We conducted grassland bird censuses during the breeding season through point counts from 2012 to 2015. The relationship between bird abundance/richness and past haying events was investigated using Generalized Linear Models whereas intra-annual effects of haying were analyzed using Generalized Additive Models. Bird abundance in a field is positively related with the surface hayed in the vicinity of that field in the previous year. However, contrasting yearly effects were found for non passerines. Also, some species prefer fields with less haying events or surface hayed (e.g. the Thekla lark), whereas others occur mostly in fields frequently managed for haying (e.g. the crested lark and corn bunting). Haying a field leads to a strong decline on bird abundance. However, the intra-annual effect of haying the surroundings of a field may depend on how optimal is the habitat in the field for the species in terms of vegetation height. We conclude that intra-annual effects of haying have higher impact on grassland birds than the inter-annual effects. Maintaining haying at low levels, by rotating haying yearly through the different fields of each farm and using partial haying, may be an adequate way to ensure an effective management of grassland bird populations.

KEYWORDS

Annual effects, haying intensification, Mediterranean dry grasslands, mowing, spontaneous grasslands.

INTRODUCTION

Grasslands in Europe are mostly semi-natural, they have emerged through centuries of low-intensity agricultural use from forests as potential natural vegetation (Bredenkamp et al., 2002; Pott, 1995). In the last decades, grassland habitats suffered strong changes in Europe as a result of shifts in agriculture priorities and European Union policies (Huyghe et al., 2014). In Mediterranean environments these changes resulted mostly from land use modification (specially, due to olive plantation; see Beaufoy, 2001) and grassland management intensification (Correal et al., 2006). Iberian Mediterranean dry grasslands were during centuries predominantly used for extensive cereal production and sheep rearing but in the last decades cattle farms became widely distributed along Mediterranean landscapes requiring different management options for grasslands. In south Portugal (Alentejo and Algarve) between 1989 and 2013, bovine numbers experienced a 107% increase (INE, 2014a). Also, the surface of the main crops used for haying (forage oats, grass-legume crops or pure legume crops) increased 34% between 1989 and 2009. In southwest Spain (Extremadura and Andalucía regions), between 1999 and 2013 bovine numbers and the surface of forage crops experienced an 11% and 65% increase, respectively (INE, 2014b; MAGRAMA, 2014).

Under adequate soil and hydrological conditions, Iberian dry grasslands can produce moderate to high primary production for hay or silage (Carpintero et al., 1991; Hernández et al., 1994; Rodríguez et al., 2002; San Miguel, 2009). New infrastructures (e.g. irrigation perimeters) and technological solutions, such as new fertilizers and more effective agriculture machinery generalized the use

grassland for hay and silage production. Nowadays, Iberian farmers are no longer willing to take risks because of the droughts that often occur under Mediterranean climate, storing biomass reserves which provide a feeding alternative in periods where grassland biomass production in farms is insufficient to ensure livestock feeding needs or when animal products are obtained from stabled livestock.

In Iberian dry grasslands haying is not confined to cereal and legume forage crops or wet meadows, occurring frequently on semi-natural spontaneous dry grasslands (grazed or not), which hold important populations of threatened or near-threatened birds at European or global level, such as the great bustard (*Otis tarda*), the little bustard (*Tetrax tetrax*) or the Montagu´s harrier (*Circus pygargus*). However, mowing machinery and mowing timings are likely to put grassland bird population at risk by causing reproductive failure through loss of nests and eggs, chick mortality or adult mortality (Gruebler et al., 2008; Vickery et al., 2001). Indeed, in temperate areas of central Europe and North America several authors suggested a link between important declines in grassland bird populations and changes in timing and frequency of hay (Green, 1997; Gruebler et al., 2008; Heckert, 1997).

Few linkages between hay management and changes in faunal populations have been established (see Perlut et al., 2006) and the knowledge on the relative importance of the processes involved is deficient, particularly in Mediterranean environments. Furthermore, there is a general lack of evidence-based landscape-scale conservation strategies that consider alternative grassland management techniques, such as rotational mosaic mowing (Buri et al., 2013). Unlike grazing, mowing is non-selective, so sward heterogeneity is

greatly reduced and the removal of grass also reduces the amount of organic matter returned to the soil (Vickery et al., 2001). Studies in temperate regions focusing on the effects of mowing and grazing on plant diversity, revealed contrasting results between studies (see, Stammel et al., 2003; Turtureanu et al., 2014). Socher et al. (2012) showed that low-intensity mowing (once a year or less) favours more species than grazing, however at higher cutting frequency, richness dropped dramatically, while higher grazing intensity had little effect on plant diversity. The management of the amount of inputs and number of cuttings may thus be responsible directly or indirectly not only for the variation observed in plant diversity but also for the high spatial variability on insect abundance at the landscape scale (Badenhausser et al., 2009; Chambers and Samways, 1998; Humbert et al., 2009), which are known to be important resources for birds in Iberian dry grasslands (see Faria et al., 2012).

In this study, we evaluate the inter-annual and intra-annual effects of haying on grassland bird diversity, abundance and spatial dynamics during the breeding season in Alentejo region (south Portugal). Our main goals were: (1) to investigate variations on bird abundance and species richness in the fields, with respect to past haying events occurred in a field (number, surface and year of last haying) and in the surroundings of a field in the previous year, assessing for differences related with contrasting weather conditions in each year and with the type of hay, and (2) to investigate the shifts in bird abundance and species richness, and therefore potential between-field movements by birds, resulting from haying a field and its surrounding area in a given year.

MATERIAL AND METHODS

Study area

The study area is located in Évora region (Alentejo province, south Portugal; -7.884902W, 38.533521N), in the Mesomediterranean biogeographic region (Rivas-Martinez et al., 2004). Climate is mostly dry, although more humid at North and West quadrants. Average annual temperatures vary from 9.6ºC in winter to 24.1ºC in summer and the annual rainfall rounds 586mm (1981-2010 period; IPMA, 2015a). This area comprises a mosaic landscape dominated by holm oak forested areas 'montados' and grasslands. Soils are mostly acidic and with low-average fertility (unpublished data). Most important land uses consist in extensive livestock grazing (mostly cattle) and cereal/leguminous crops for hay production. Cereal crops for grain are nowadays less common due to recent conversion of farms for beef production. Irrigated pastures are also rather common in this region, although marginal in surface compared to dry grasslands. The mean field size in the study area was around 70 ha.

As mentioned above, there are no official mowing statistics for the region of Évora and therefore the only data available refer to the fields monitored by our team during these four years of study (Table 1). All mown fields during these four years were used for hay production. The meteorological statistics were very different, both in terms of rainfall and temperatures (IPMA 2015b), potentially affecting the entire process of haying and bird distribution and are presented in Table 1.

Table 1 - Haying and weather statistics for the 2012-2015 period in Évora region.

Statistics	2012	2013	2014	2015
Haying				
Fields controled	50	50	52	41
Fields with tall/dense vegetation with potential for haying	10	17	23	16
Fields partly or fully hayed	3	12	15	11
Haying start date	16-May	06-May	06-May	05-May
Weather				
Winter* rainfall (mm)	25.3	168.3	291.8	89.2
Spring** rainfall (mm)	46.9	225.3	160.0	77.4
Winter average minimum temperature (ºC)	2.5	7.8	5.2	3.6
Winter average maximum temperature (ºC)	14.9	11.0	14.5	14.2
Spring average maximum temperature (ºC)	6.5	7.7	7.6	7.8
Spring average minimum temperature (ºC)	19.1	17.8	19.4	20.9

*Winter (December-February), **Spring (March-April)

The study area is partly included in the Special Protection Area for birds of Évora. It holds important populations of protected grassland bird species such as the little and great bustards, Montagu's harrier, black-bellied sandgrouse (*Pterocles orientalis*) and the calandra lark (*Melanocorypha calandra*). No special regulation on mowing is applied inside the Special Protection Area.

Field methodology

We conducted grassland bird censuses through point counts during four consecutive breeding seasons from 2012 to 2015. Bird counts were made in the first three and a half hours after sunrise and in the last two and a half hours

before sunset, in the last fortnight of April and repeated in the last fortnight of May. A radius of 250m around the point count station and a count period of 15 minutes were assumed, recording for the location and number of individuals of each species displaying clear territorial or nesting behaviour and adjusting if necessary the geographical location of the territories (this procedure is particularly important in high density areas were birds spend most of their time chasing each other). The species and bird groups considered are presented in Table 2. In order to obtain homogenous sampling areas, counts were only made in fields with enough size to fit the whole counting area. In total we performed census in 45 fields in 2012, 45 fields in 2013, 47 fields in 2014 and 39 fields in 2015. Due to limitations on the cartography available for haying (notably the dates of mowing), we only considered analysing intra-annual effects of haying in 35 fields in 2012, 37 fields in 2013, 37 fields in 2014 and 35 fields in 2015.

Information on haying was mostly collected during field work or provided by land managers. If necessary, the surface mown in each field was corrected using the aerial photos of the region. Two types of hay were considered: cereal-based crops and pastures/fallow land. Fields sown with grasses such as raygrass and alfalfa/clover are quite rare in Évora region and thus were not considered.

Vegetation surveys were conducted after bird counts, in the same day or at most 2 days later. Vegetation height was measured within a 50cmx50cm square, using 18 random sampling replicates disposed around each point count station. All remaining independent variables collected are presented in detail in Table 3.

Table 2 - Species considered for the study, respective phenology status and bird groups. The species analysed individually (representative in the sample) are presented.

Species	Fenology status	Bird group*	Representative in the sample
Montagu´s Harrier *Circus pygargus*	Breeding	NP,GN	
Black-shouldered Kite *Elanus caeruleus*	Resident	NP,NGN	
Lesser Kestrel *Falco naumanni*	Breeding	NP,NGN	
Common kestrel *Falco tinnunculus*	Resident	NP,NGN	•
Red partridge *Alectoris rufa*	Resident	P,GN	
European quail *Coturnix coturnix*	Breeding	NP,GN	•
Little bustard *Tetrax tetrax*	Resident	NP,GN	•
Great bustard *Otis tarda*	Resident	NP,GN	
Eurasian stone-curlew *Burhinus oedicnemus*	Resident	NP,GN	
Black-bellied sandgrouse *Pterocles orientalis*	Resident	NP,GN	
Calandra lark *Melanocorypha calandra*	Resident	P,GN	•
Short-toed lark *Calandrella brachydactyla*	Breeding	P,GN	
Crested lark *Galerida cristata*	Resident	P,GN	•
Thekla lark *Galerida theklae*	Resident	P,GN	•
Tawny pipit *Anthus campestris*	Breeding	P,GN	
Zitting cisticola *Cisticola juncidis*	Resident	P,GN	•
Southern grey shrike *Lanius meridionalis*	Resident	P,NGN	•
Corn bunting *Emberiza calandra*	Resident	P,GN	•

*Passerine (P), Non- Passerine (NP), Ground-nesting (GN) and Non ground-nesting (NGN).

Table 3 - Variables used to model dry grassland bird response to haying management at two temporal scales (inter-annual and intra-annual).

Variable	Description
Inter-annual	
Year	Factor variable indicating the year where field works took place.
LastHayF	Year of last haying in the field. Varying from 0 if last haying occurred in the previous year, to 3, if last haying occurred four years ago or more.
NHayF3Y	Number of years that the field was hayed in the previous three-year period.
PHayF3Y	Average percentage of field that was hayed in the previous three-year period.
PHayF1Y	Percentage of field that was hayed in the previous year.
PHayS1Y	Percentage of a 300 meter buffer around a field that was hayed in the previous year.
Intra-annual	
PHayField	Percentage of the counting area that was hayed.
PHaySurr	Percentage of a 500 meter buffer around the counting area that was hayed.
VegHeig	Mean vegetation height measured at a field within a 50x50 cm square, using 18 sampling replicates randomly disposed around each point count station. Factor variable with four vegetation classes: (1) 0-15 cm, (2) 15-30 cm, (3) more than 30 cm and (4) vegetation hayed.

Data analyses

Inter-annual effects

The relationship between bird abundance/richness and past haying events was investigated using Generalized Linear Models (GLM, McCullagh and Nelder, 1989), considering a Poisson distribution for the data. When overdispersion was detected in models, the standard errors and p-values

estimates were corrected using quasi-GLM models. The variance in quasi-GLM models is given by $\phi \times \mu$, where μ is the mean and ϕ the dispersion parameter. Following the recommendation of Zuur et al. (2009) the models with ϕ over 1.3 were corrected for overdispersion. The dependent variables used were (a) the territory abundance for each species (Table 3) and for specific groups of birds (passerines, non-passerines, ground-nesting birds, non ground-nesting birds and all species), and (b) the species richness for the same groups of birds mentioned behind. The maximum abundance/richness values between April and May counts were chosen for the analysis. We defined *a priori* five independent variables of interest, four variables describing haying events at the field level: (1) the last year of haying, (2) the number of years of haying in the previous three-year period, (3) the surface used for haying in the previous three-year period and (4) the surface used for haying in the previous year; and one variable describing haying events in the surroundings of a field (5) the surface used for haying in the previous year within a buffer of 300 meter around the field (for variable names and descriptions see Table 3). Although the descriptive variables collected at field level have different biological meaning and management application, they presented non-negligible levels of collinearity (correlation values between 0.65 and 0.85), which may lead to overfitting problems and misleading results when including all variables simultaneously in GLM models. To overcome this problem we restricted model ranking/selection to four GLM models and respective sub-models:

M1: maxBirdAprilMay ~ (*LastHay* + *SHayS*) *x Year*

M2: maxBirdAprilMay ~ (*NHayF3Y* + *SHayS*) *x Year*

M3: maxBirdAprilMay ~ (PHayF3Y + PHayS) x Year

M4: maxBirdAprilMay ~ (PHayF1Y + PHayS) x Year,

where, *maxBirdAprilMay* represents the maximum abundance or richness of the species and groups considered recorded in April or May.

These models allowed us to assess the response of each bird species/group to haying both on a temporal scale (e.g. number of years to last haying, *M1* model) and spatial scale (surface used for haying and number of haying events). Also, we previously explored data for potential differential responses of birds to haying of different types of hay (cereal-based crops and pasture/fallow land were the types of hay considered).

Model ranking and selection was achieved by calculating Akaike's Information Criterion corrected for small sample size (AICc) or Akaike's Information Criterion for overdispersed count data, corrected for small sample (QAICc), for all possible combinations of variables of M1 to M4 models. Models with the lowest AICc/QAICc and within less than 2 units of ΔAICc/ΔQAICc were selected as best models and considered similar in performance (Burnham and Anderson, 2002). All calculations were performed using R for Windows (R Development Core Team, 2007).

Intra-annual effects

Potential between-field spatial dynamics on bird abundance and richness resulting from haying were investigated using Generalized Additive Models, considering a normal distribution for the data (GAM; Wood, 2008). The

dependent variables used were the variation in bird abundance and species richness between April and May (before and after haying started). The use of additive modelling relates to the fact that the univariate exploratory analyses made previously revealed the existence of non linear responses by birds. The species and groups tested were the same considered in section 2.3.1. The independent variables used were (1) the surface used for haying in the field and; (2) the surface used for haying within a buffer of 500 meter around the bird counting area. We opted to use the counting area as a reference to characterize the surface of haying in the surroundings and to use a larger buffer (500 meter instead of the 300 meter used in the inter-annual analyses), because some fields are considerably larger than the count area. The use of the field as a reference for characterizing the surroundings would imply that an important proportion of the potential bird movements from the areas mown in the surroundings would expectably be directed to an area of the field that may be far from the counting area, hampering the detection of this pattern.

Potential between-field dynamics on bird abundance and richness resulting from haying in the surroundings of a field are expected to depend on the vegetation structure available at the new destination field. This effect was accounted for in models using the vegetation structure as an interaction term, where this variable consists in a factor with four classes of vegetation structure (see Table 3). The global model computed was:

$$\textit{BirdMay-BirdApril} \sim s(PHayFiel) + s(P\textit{HaySurr}) + s(P\textit{HaySurr},by=\textit{VegHeig}) + \textit{VegHeig}$$

where, *BirdMay-BirdApril* represents the difference in the abundance or richness of the species and groups considered.

Model ranking and selection was performed in a similar manner described for the inter-annual effects analysis.

RESULTS

Inter-annual effects

Although the existence of potential differences in bird response to the type of hay produced (pasture-fallow land *vs.* cereal based forages) was previously evaluated, the models generated were not significantly improved by including this variable, and thus no further distinction on the type of hay was considered in the analyses. Results indicate that the abundance of birds in a field is positively related with the surface hayed in the vicinity of that field in the previous year. This pattern was found for the overall abundance, abundance of passerines, non-passerines, ground-nesting birds (Table 4) and for the calandra lark (Table 5). However, opposite trends were found for non passerines between 2014 (warm and humid year) and 2012 (the driest year).

Conversely, the abundance and richness of non-ground nesting birds (shrikes and small birds of prey) was lower in fields whose the surroundings presented in the previous year an higher area hayed. However, opposite trends were found between 2013 (cold and humid year) and 2012 (the driest year). The abundance of ground-nesting birds was also higher in fields more recently hayed.

Table 4 - Best GLM models for the response of grassland bird groups to the inter-annual management of haying (Δ(Q)AICc<2). The coefficients, the (Q)AICc for each model and the statistical significance of each variable are presented (*p<0.05, **p<0.01, ***p<0.001).

Bird group	Year	PHayS1Y	LastHayF	PHayF3Y	PHayF1Y	PHayS1Y:Year				LastHayF:Year				pseudoR^2	(Q)AICc	Δ(Q)AICc	Weight
						12	13	14	15	12	13	14	15				
Bird Abundance (Overall)	•*	0.53*												0.08	713.80	0.00	0.18
	•*	0.51*	0.03											0.09	714.00	0.20	0.17
		0.40												0.03	714.70	0.84	0.12
		0.37	0.03											0.04	715.10	1.23	0.10
	•	0.47*								-0.05	0.12	0.12*	0.10	0.13	715.20	1.37	0.09
Passerine abundance	•**	0.46	0.04											0.12	672.30	0.00	0.26
	•**	0.48*												0.11	672.40	0.13	0.24
	•**		0.04											0.10	673.80	1.58	0.12
Non-passerine abundance	•*	1.03*		-0.58										0.10	520.40	0.00	0.26
		1.17**		-0.56										0.06	521.40	1.05	0.16
	•			-0.57		1.71*	-0.68	-2.84*	-0.01					0.12	521.60	1.21	0.14
	•*	1.09*												0.08	522.00	1.65	0.12
Ground-nesting abundance	•***	0.59*	0.04											0.25	660.90	0.00	0.39
	•***	0.62**												0.24	661.90	0.99	0.24
	•***		0.05*			1.03*	-0.40	-1.16	0.06					0.28	662.80	1.85	0.16
Non ground-nesting abundance	•*				-0.66	-5.66**	7.39*	1.72	2.99					0.24	331.10	0.00	0.30
	•					-5.51**	7.23**	1.20	2.63					0.23	331.30	0.20	0.27
	•**	-2.82**			-0.63									0.20	331.80	0.70	0.21
	•**	-2.93**												0.19	331.90	0.84	0.19
Non ground-nesting richness	•*	-2.89**			-0.64									0.16	303.70	0.00	0.27
	•*	-3.00**												0.15	303.70	0.00	0.27
	•*				-0.67	-5.66**	7.20*	1.74	3.30					0.19	304.10	0.40	0.22
	•*					-5.51**	7.03*	1.20	2.94					0.17	304.20	0.53	0.21

Table 5 - Best GLM models for the response of grassland bird species to the inter-annual management of haying. The coefficients, the (Q)AICc for each model and the statistical significance for each variable are presented (*p<0.05, **p<0.01, ***p<0.001). The models are within Δ(Q)AICc < 2.

Species	Year	PHayS1Y	PHayF1Y	NHayF3Y	LastHayF	PHayS1Y:Year				LastHayF:Year				pseudoR^2	(Q)AICc	Δ(Q)AICc	Weight
						12	13	14	15	12	13	14	15				
Corn bunting	•***				0.07*									0.19	502.50	0.00	0.24
	•***	0.49			0.07*									0.21	502.70	0.18	0.22
	•									-0.04	0.23*	0.14	0.08	0.23	503.70	1.18	0.13
	•	0.46								-0.03	0.23*	0.12	0.07	0.25	504.20	1.73	0.10
	•***	0.55												0.17	504.40	1.91	0.09
Crested lark	•**	-0.64		-0.41***										0.19	269.90	0.00	0.45
	•**			-0.42***										0.20	270.50	0.68	0.32
Thekla lark				-0.35***										0.12	542.70	0.00	0.43
		-0.45		-0.35***										0.12	543.60	0.92	0.27
	•			-0.35***										0.14	544.30	1.61	0.19
Calandra lark		1.87*												0.06	274.10	0.00	0.55
		1.91*	0.41											0.07	275.50	1.39	0.28

The crested lark presented higher abundances in fields hayed more frequently. On the other hand, the Thekla lark presented higher abundances in fields with less haying events in the previous years. The corn bunting was more abundant in fields mown more recently.

The selected models for the little bustard and the zitting cisticola were mostly supported by the annual variation on the abundance of the species, but none of haying variables fitted in models. No relationship was found between past haying events with species richness (overall, passerine, non-passerine and ground-nesting birds) or the remaining species.

Intra-annual effects

The data were previously evaluated for between-year differences in bird response using a mixed modelling approach, but the models generated were not significantly improved by including this effect, therefore we carried out a GAM modelling approach. The results indicate that the occurrence of haying in a field leads to a strong decline in the overall, passerine and ground nesting bird abundance (Table 6). Similar results were obtained at species level for the corn bunting (relationships are linear thus GAM plots are not presented).

Table 6 - Summary results of GAM models for the response of grassland bird abundance and richness to the intra-annual management of haying. The AICc, ΔAICc, Akaike weights and the statistical significance for each variable are presented (*p<0.05, **p<0.01, ***p<0.001). The models shown are within ΔAICc < 2.

Variable	VegHeig			s(PHayFiel)	s(PHaySurr)	s(PHaySurr, by = VegHeig)				pseudoR^2	(Q)AICc	Δ(Q)AICc	Weight
	15-30	30+	Hay			0-15	15-30	30+	Hay				
Group													
Bird abundance (Overall)	1.00	1.58	-3.82***							0.22	766.4	0.00	0.28
				•***						0.20	766.8	0.47	0.22
	1.00	1.60	1.96	•						0.22	767.7	1.33	0.14
	1.01	1.60	-3.46**		•					0.22	768.1	1.72	0.12
Passerine abundance				•***						0.18	775.8	0.00	0.32
	0.95	1.58	-3.69***							0.20	777.2	1.32	0.16
	0.95	1.60	-1.13	•						0.24	777.6	1.81	0.13
Ground-nesting abundance				•***						0.19	776.9	0.00	0.27
	1.15	1.42	-3.85**							0.21	778.0	1.08	0.16
	1.15	1.44	-1.55	•						0.24	778.6	1.71	0.11
				•***	•					0.19	778.7	1.85	0.11
	0.96	1.82*	-3.03*			•	•	•	•	0.26	778.8	1.94	0.10
Species													
Corn bunting	1.14	1.61*	-2.52**							0.21	702.5	0.00	0.39
	1.14	1.62*	-1.00	•						0.21	703.8	1.29	0.20
Zitting cisticola	0.16	0.68**	-2.23	•***		•	•*	•*	•	0.33	421.0	0.00	0.80
European quail	0.25	0.57*	0.04			•	•	•***	•	0.14	397.6	0.00	0.33
						•	•	•***	•	0.10	397.9	0.32	0.28

An increase in the abundance of the zitting cisticola was found in fields where the counting area was hayed up to 50%, decreasing from this percentage (Table 6 and Fig. 1). Furthermore, in fields with vegetation between 15 and 30 cm, the abundance of this species declines when the surrounding area is hayed (Table 6 and Fig. 2). For the fields with vegetation taller than 30 cm, the zitting cisticola abundance peaked when around 15% of the surrounding area was hayed, decreasing sharply when hayed surface increased further (Table 6 and Fig.2).

We found no relationship between the abundance of the European quail and the area hayed in the field (Table 6). However, in fields with vegetation taller than 30 cm, the abundance of this species strongly increased following severe haying in the surrounding area (Table 6 and Fig.3).

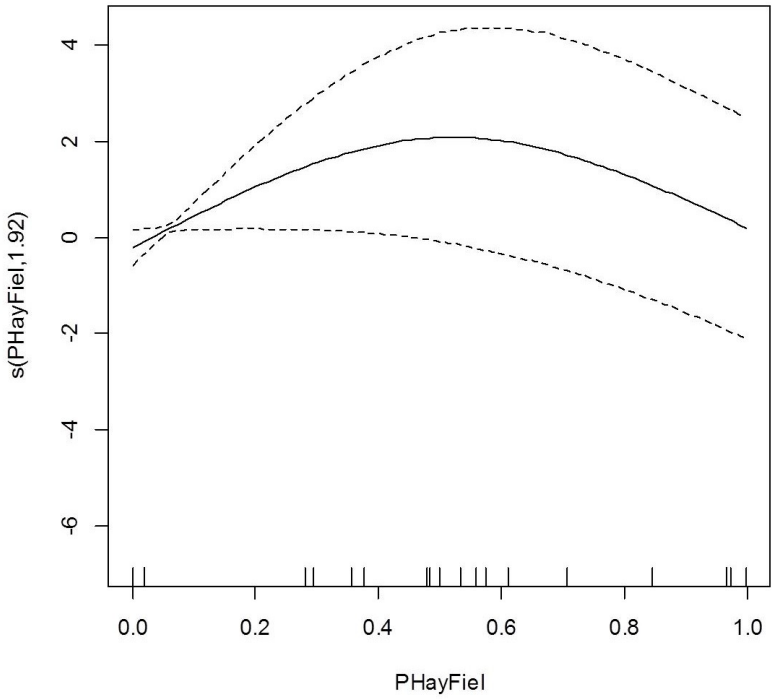

Fig. 1 - Relationship between zitting cisticola abundance and the area hayed in the counting station area (*PHayFiel*), represented by the smoothing curve resulting from the corresponding GAM model. The vertical axis represents the contribution of the fitted values to the response variable. The dotted lines are 95% confidence bands.

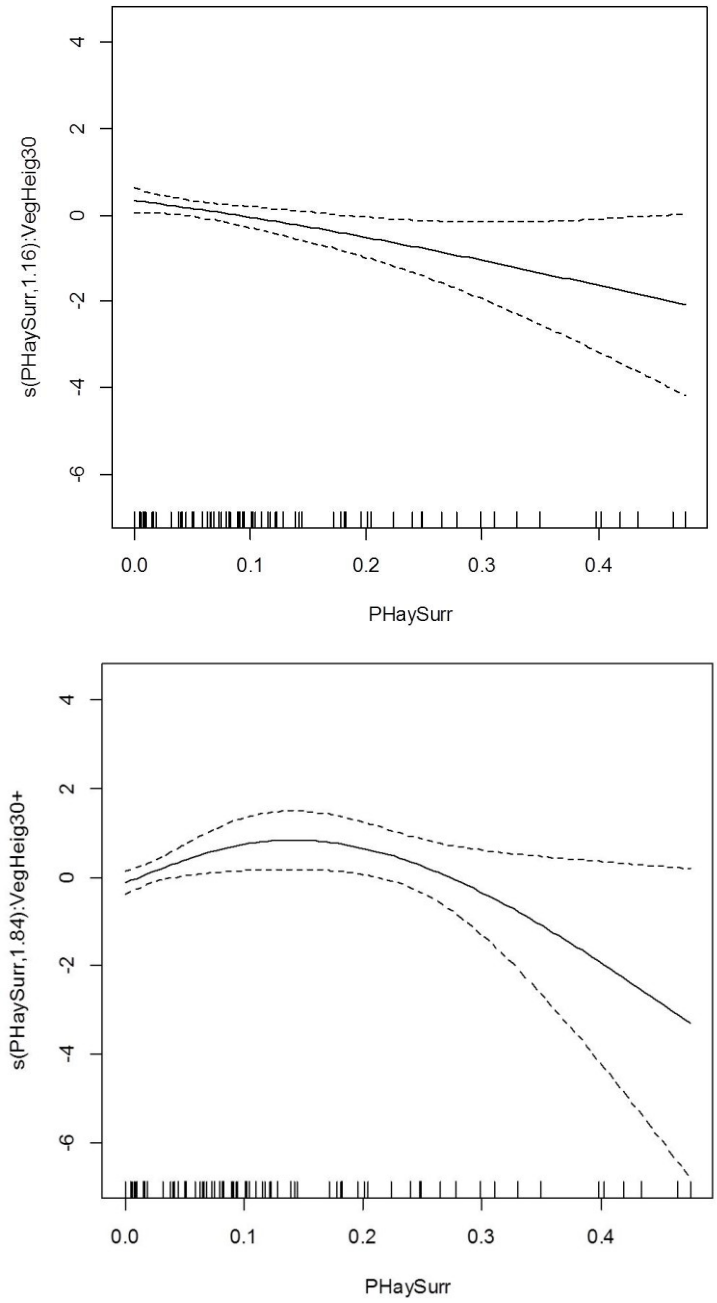

Fig. 2 - Relationship between zitting cisticola abundance and the area hayed in the surrounding of count stations (*PHaySurr*) represented by the smoothing curve resulting from the corresponding GAM models for the vegetation height classes 15-30 cm (above) and more than 30 cm (below). The vertical axe represents the contribution of fitted values to the response variable. The dotted lines are 95% confidence bands.

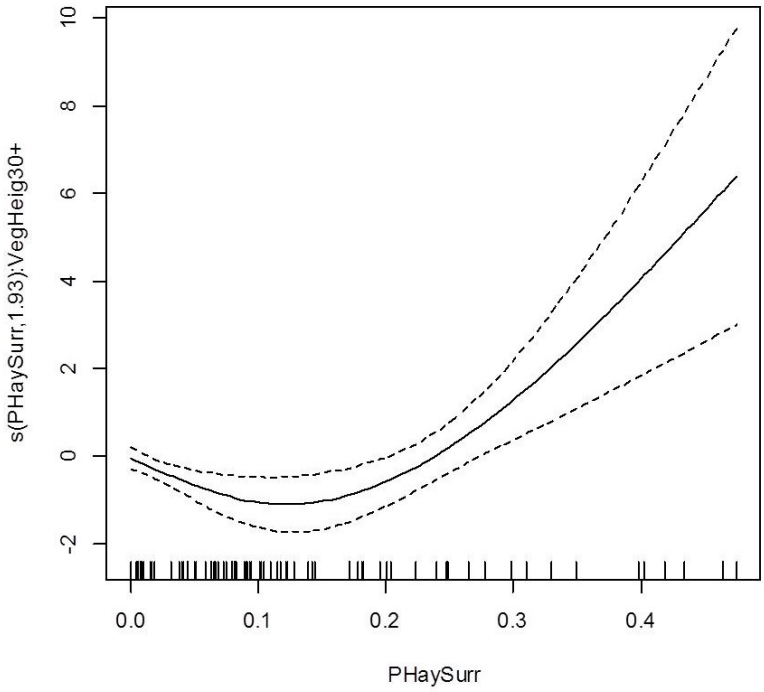

Fig. 3 – Relationship between European quail and the the area hayed in the counting area (*PhaySurr*) represented by the smoothing curve resulting from the corresponding GAM modelfor the vegetation height class more than 30 cm. The vertical axe represents the contribution of fitted values to the response variable. The dotted lines are 95% confidence bands.

No relationship was found between species richness (overall or group based) and abundance of the remaining groups/species considered with haying in the field or in the surrounding of the field.

DISCUSSION

The landscape structure surrounding a field may influence abundance and productivity of birds (see Devictor and Jiguet, 2007 for an effect at large spatial scale, Guerrero et al., 2012). However, in grassland habitats this effect has rarely been tested (see Söderström et al., 2001; Sovada et al., 2000). The

results of this study indicate that the area occupied by hayed fields in grassland landscapes influences the between-year abundance of grassland birds.

The weather conditions in each year may determine different attractiveness of formerly hayed fields and opposite effects in bird responses, as seen for instance for non-ground nesting birds. This effect is possibly dependent on soil properties influencing the quality of hayed fields in terms of resources for birds, notably vegetation density, and consequently arthropod abundance. In the case of ground-nesting species, vegetation density may also affect nest site suitability (Donald et al., 2001; Silva et al., 2014) which may explain the contrasting effects between the two guilds found in this study.

Some species prefer fields with less haying events or surface hayed, whereas others occur mostly in fields frequently managed for haying. These contrasting responses between species were also found in other studies in temperate regions (see, Dale et al., 1997; Igl, 2009; Roth et al., 2005). The ecology of the species is likely to be in the basis of these preferences. For instance, corn buntings were historically linked to the use of meadow grasslands for hay production in temperate Europe, but they have markedly declined due to meadow management intensification (see Perkins et al., 2013, for an extensive discussion on this subject). Similarly, crested larks occur mostly in cultivated areas (Santos and Suarez, 2005), where mowing is potentially used more frequently. On the other hand, Thekla larks prefer less disturbed habitats such as old fallows, in most cases with sparse shrubs (Reino et al. 2010, Santos and Suarez, 2005) and thus with low potential for haying. The preference of calandra larks for hayed surroundings in the previous years

may reflect their avoidance for fields with sparse shrubs (Reino et al., 2010), since haying is an effective measure to control shrub invasion in grasslands.

The intra-annual results indicate that haying a field generates a strong decline on grassland bird abundance, particularly that of corn bunting. This contrasts with the study by Roth et al. (2005) in temperate regions of North America where after haying, a re-establishment of birds was noted. It should be stressed out that in our study area hay can stay on some fields for several days spread over the field without being raked (the availability of haying machinery is limiting for most of farmers). Consequently hay works can last up to 15 days ending in most cases with the stubble completely dry due to high temperatures. Anyway, temperatures over 30ºC in May often dry out hay stubbles in 10-15 days, triggering the end of the breeding season and therefore, even when tall/suitable stubbles for renesting are produced the re-establishment of birds is unlikely.

As it happens with the corn bunting, a similar decrease in the abundance of the zitting cisticola and the European quail following haying works would be expected. We believe that, as seen with other grassland species in North America (Nocera et al. 2007), zitting cisticola nests are placed in most cases in tall vegetation along drainage ditches hardly accessible to haying machinery (pers. obs). Concerning the European quail, unpublished data from our team indicates that this is the species with higher nest survival to haying works; therefore, it is expected that some individuals remain in hayed fields, particularly when partial haying was carried out. Partial field haying as identified by our additive models may enable an easier access to insects, both ensuring the breeding requirements of the existing pre-haying reproductive pairs in the field

and attracting more birds from surrounding ones. Also, partial haying may have a similar effect of leaving unmown refuge areas as described by Broyer (2003), thus helping to reduce the effects predation following mowing.

Theoretically, birds depending on tall grassland nesting in sub-optimal habitats would be negatively affected by haying in the surrounding area due to the potential loss of resources. This pattern was supported only for the zitting cisticola, since the abundance of this species in fields of intermediate vegetation height (15 and 30 cm) declined as the surrounding area hayed increased. On the other hand, both for the zitting cisticola and the European quail, fields with optimum habitats for these species (vegetation taller than 30 cm; Cramp and Simmons 1980; Cramp and Simmons, 1983) and hayed surroundings showed an increase in their abundance. This result evidences shifts between hayed fields and fields with optimum vegetation although, for the zitting cisticola, this pattern only applies under low levels of surrounding area hayed.

CONCLUSIONS

We conclude that short-term effects (intra-annual) of haying have higher impact on grassland birds than the long-term effects (inter-annual). The within year effects of haying are mostly negative for grassland birds, particularly for those species dependent on tall grasslands, decreasing their abundance in fields due to the loss of breeding habitat, so that birds are forced to seek for new breeding fields or even resuming their breeding season. Moreover, according to the data collected in a parallel study by our team and to other studies in grassland habitats (Gruebler et al., 2008), adult nesting birds may not

survive to haying machinery, which negatively impacts local breeding populations.

On the other hand, the current trends of haying in Mediterranean dry grassland landscapes may actually be positive for some bird species as supported by our results. It is possible that in these cases, cutting for hay production provides an analogous effect to that of cutting for grain production (which occurs in average 4-5 weeks later). If that was the case, hay stubbles act as a “replacement” habitat of mixed cereal-sheep systems stubbles which used to have a larger extent in the region in the recent past. Therefore, maintaining haying at low levels, both in an inter-annual scales, rotating haying yearly through the different fields of each farm and in a within field scale (using partial haying), may be an adequate way to ensure an effective management of Mediterrranean grassland bird communities.

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3. LINKING PLANT COMPOSITION AND ARTHROPOD ABUNDANCE TO ESTABLISH LITTLE BUSTARD BREEDING REQUIREMENTS IN PASTURELAND DOMINATED LANDSCAPES

ABSTRACT

Most research on steppe bird habitat selection has been focused on the effects of management regimes or vegetation structure. However, much less is known on how plant composition is related with steppe bird occurrence. We investigated microhabitat of little bustard territorial males and females during the nesting and chick-rearing season in areas with dominance of pastureland focusing on plant composition. We searched for relationships between preferred vegetation and arthropod abundance in order to identify the contribution of different vegetation typologies in providing essential trophic resources for the species. Surveys of little bustards were made using car and foot transects. Plant composition was obtained within a 50x50 cm square at four sampling replicates and arthropod availability was sampled using a sweep net. Statistical procedures were conducted in three steps: (1) analysis of variance was used to identify at univariate level the plant composition and arthropod variables that were significantly related with both male and female occurrence sites; (2) principal components analysis was performed using the variables with significant results at univariate level; (3) model averaging on generalized linear and mixed models was applied to evaluate the selection probability of each principal component. The species occurs in sites with high floristic richness and high abundance of Fabaceae species, although plant composition differs from male to female sites. These variables were found to be crucial to provide higher abundances of arthropods, notably of Acrididea, Formicidae and some groups of Coleoptera which are decisive for the selection of displaying or female breeding sites.

KEYWORDS

Tetrax tetrax, grasslands, plant richness, microhabitat selection, Acrididae, Fabaceae.

INTRODUCTION

Traditionally, most research on the steppe bird habitat selection has been focused on the effects of management regimes (Brotons et al. 2003; Lane et al. 2001; Morales et al. 2005) or vegetation structure (physiognomy; García et al. 2006; Morales et al. 2008; Silva et al. 2007). These variables were recognized as crucial factors not only for the distribution of steppe birds but also from a synecological or community level point of view (e.g. Morales et al. 2008).

However, much less is known on how plant composition is related with steppe bird occurrence or abundance (see for instance, Serrano and Astrain 2005). Furthermore, there is little information on how vegetation composition direct and indirectly contributes to provide resources, in particular arthropod abundance, which was found to be a crucial resource during the nesting period (García and Arroyo 2005; Jiguet 2002; Rocha et al. 2005) and is known to be influenced by plant species composition (Koricheva et al. 2000, Predini et al. 1996).

Mediterranean dry grasslands present highly rich and diverse plant communities. These high levels of plant diversity are likely to result from traditional cultivation and livestock management that historically dominated Mediterranean agricultural landscapes, contributing to the present importance of Iberian steppe bird populations at global scale (Suárez et al. 1997). However, recent crop and grazing intensification have threatened these grassland habitats resulting in habitat fragmentation, introduction of non-native species and changes in the composition of existing plant communities (see Groves and Di Castri 1991, for an extensive discussion on this subject), which reinforces the

need for studies combining the ecological and habitat management perspectives.

In Iberian dry grasslands, one of the steppe birds more clearly affected by these intensification-driven processes is the little bustard (De Juana 2009), a Paleartic species classified as ‘‘SPEC 2’’ at European level (Birdlife International 2004) and ‘‘Near Threatened’’ at global scale (IUCN 2011). The little bustard is a sexually dimorphic species that breeds in exploded leks (Jiguet et al. 2000). Ecological segregation associated with sex and based on vegetation structure was described by Morales et al. (2008) in cultivated landscapes, although plant composition at occurrence sites, which might be closely associated to habitat management, was not taken into account.

In this study we investigate microhabitat of territorial males and females during the nesting and chick-rearing season in areas dominated by pastureland. Our first hypothesis is that habitat segregation associated with sex also occurs in pastureland habitats and it is partly based on plant composition. We discuss potential resource control by males in terms of vegetation and arthropod assemblage at occurrence sites. Secondly, we explore the potential relationships between preferred vegetation composition and arthropod abundance in order to identify the contribution of different vegetation typologies in the provision of essential trophic resources for the species and particularly growing juveniles. More specifically, we aimed to identify the plant species that can be most valuable for pasture improvement and those who should be avoided in such management actions. Lastly, we discuss the implications of results on how Mediterranean extensive pastures should be managed in order

to maintain their suitability as breeding habitat for little bustards and other steppe birds.

MATERIAL AND METHODS

Study area

The study area is located in the SW of Portugal (38°29'N, 8°20' W, 137 m a.s.l.) in the Mesomediterranean and Termomediterranean biogeographic regions (Rivas-Martinez et al. 2004). The area is included in the NATURA 2000 national list of sites (Site of Community Importance of Cabrela, hereafter SCI of Cabrela) and in the European list of Important Bird Areas (Cabrela IBA; Costa et al. 2003). Climate shows both ocean and continental influences, shifting from sub-humid to dry. Average annual temperatures vary from 15.6 to 16.3 º C and annual rainfall between 574 and 708 mm (SNIRH 2007). The study area is part of a mosaic landscape dominated by cork/holm oak (*Quercus suber*/*Q. rotundifolia*) forested areas, grasslands and river valleys. Soils are mostly acidic and with diverse levels of fertility (IA 1980; IDRhA 1982).

The study area has a surface of 6983ha, corresponding to six patches of grassland habitat and equivalent to 55-65% of the SCI/IBA of Cabrela grassland area, which is ca.11-12% of total area of SCI/IBA of Cabrela (Fig. 1). The most important land uses are livestock grazing (mostly cattle) and extensive cereal crops. Pastures occupy ca. 40-50% of the area (55-65% considering pastures growing in the understory of sparsely forested areas), whereas irrigated lands occupy less than 5% of total surface. Other land uses include cereal fields (10-25%), improved pastures (5%), dense forests (5%) and shrublands (5%).

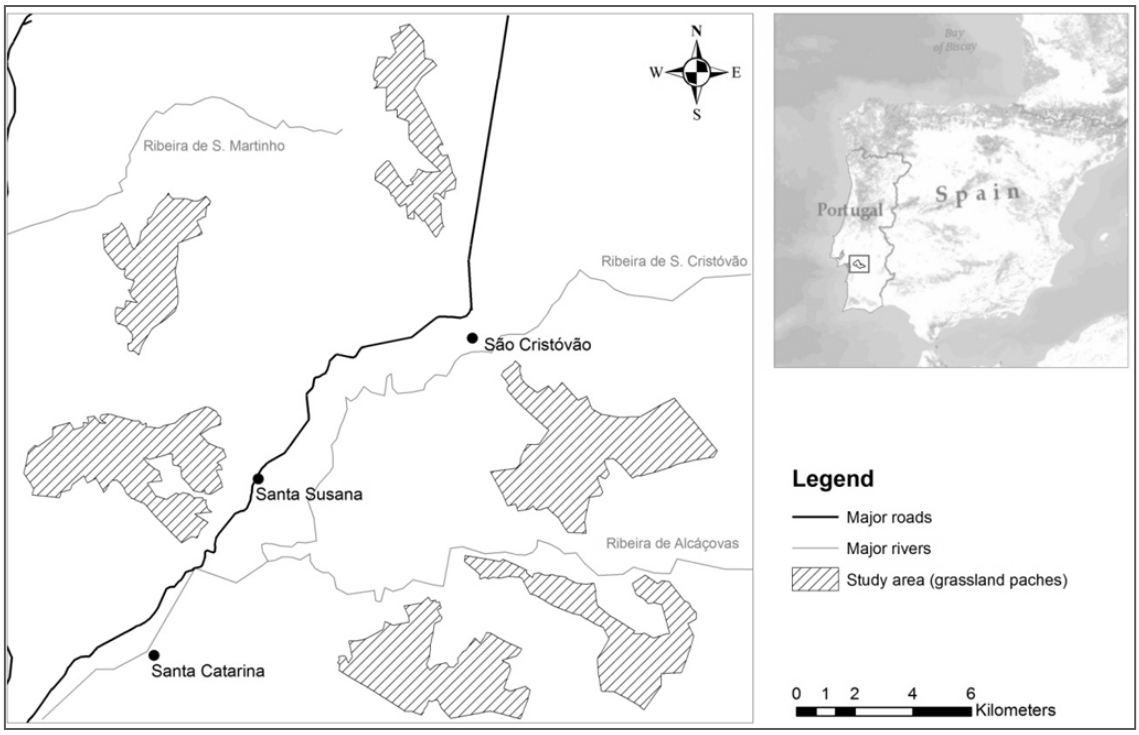

Fig. 1 - Geographical location of the study site and of the surveyed grassland patches).

Field techniques

Surveys of little bustard territorial males were conducted twice during the month of May of 2003 and 2004. This period was selected because previous studies conducted in the area have shown that male breeding numbers are highest at this time (Faria and Rabaça 2004). For the purpose of this study we only used data from the second visits (19-25 of May of 2003 and 17-24 of May of 2004), which corresponded to the peak o male displaying activity. The land surface covered in each period was 4041 ha in the first year and 4653 ha in the second. The difference in the surface sampled between years was related mostly to logistic constraints in the access to private property in the first year, which were overcome in the second year, allowing covering a larger extent of grassland. Spatial distribution of males was assessed using the methodology

adopted by Leitão and Costa (2001) and Wolff et al. (2001). Since little bustard densities are very low in the study area, we used surveys on 4x4 vehicle to get a full mapping of male displaying sites (exceptionally, a few areas with hard tracks were surveyed on foot). Surveys were carried out during the first three and a half hours after sunrise, stopping every 500 meters and/or at the top of the hills to search with binoculars or spotting scope. The final little bustard male dataset consists of 179 sampling sites: 93 territorial male displaying sites (sites where males were recorded in displaying behaviour) and 86 random sites (absence data). Male displaying sites are mostly easy to locate in the field. These are frequently one-meter radius circles with depleted vegetation due to trampling where faeces and feathers can also be easily found. Displaying sites are expected to be a good indicator of grassland use since their location was mostly coincident in the two surveys performed during the month of May. The spatial arrangement of random sites was generated automatically in GIS software (ArcMap). In this procedure, the minimum distance between a random site and the adjacent random/displaying site was set to 200 m in order to minimize potential problems of spatial autocorrelation. The number of random points defined was similar to the number of males observed during the first visit of May.

Female surveys were conducted in 2003, 2004 and 2006, during nesting and chick rearing periods, from the last week of April to the end of June. The land surface covered in each year was 1993 ha in 2003, 1468 ha in 2004 and 1590 ha in 2006. Spatial distribution of females was assessed using a methodology similar to that adopted by Wolff et al. (2002). Fields were sampled by means of foot surveys walked by 2-3 observers distancing 50m from each

other, searching regularly for walking or flushed females. The difference in the surface covered between years was related with logistic constraints, notably the existence of aggressive cattle in some fields but mostly related with the number of collaborators available for the sampling of fields each year. Since the number of females was expected to be low, to improve chances of detecting females we only sampled fields distancing less than 700 m from the nearest male displaying site. Sexual differentiation between female and juvenile male was made by experienced surveyors, taking into account bird morphological traits and behaviour (see Jiguet and Wolff 2000). Flushed females were carefully controlled in order to minimize potential double counts. Surveys were carried out during the first 3-4 hours after sunrise and 2-3 hours before sunset. The female data set comprises 115 sampling sites: 52 female sites and 63 random sites. The location of females obtained in foot surveys is also likely to be a good indicator of grassland use, due to short mobility of females during incubation and early chick rearing period, as supported by radiotracked females (N. Faria, unp. data). The spatial arrangement of random sites was generated automatically in GIS software (ArcMap). In this procedure, the minimum distance between a random site and the adjacent random/female site was set to 200 m in order to minimize potential problems of spatial correlation. The criteria to define the number of random sites sampled was the number of females expected, based on the total number of males in the surveyed fields and the number of fields that we could actually sample. A ratio 1:1 was expected between males and females.

The information on plant composition was obtained each year from four sampling replicates arranged around the sampling site (10 meter distant)

according to the four main cardinal points. Here, the presence/absence of each plant species and a clover (*Trifolium* spp.) cover estimate were obtained within a square of 50x50 cm (Sutherland 1996). The estimative of clover cover was taken because of its potential importance for little bustards (see for instance Salamolard and Moreau 1999). From this data we calculated the species richness and an abundance index for each plant species ranging from 0 to 4, related to the occurrence of each plant species at the four sampling replicates.

Insect sampling was carried out using a 45 cm diameter sweeping net (Sutherland 1996). Insect sampling was made by sweeping the ground vegetation along two replicates of 20 meter long, crossing the sampling site. In order to provide an accurate sampling of ground dwelling insects, vegetation was swept the closest possible to the ground by dragging the sweeping net. In spite of this method could not be the best one for sampling arthropods living underground, we preferred it to pitfall traps because 1) it requires a less intensive field effort to collect data; 2) pitfall traps are easily damaged by cattle trampling and 3) pitfall traps are referred as quite inefficient for sampling Orthoptera in dense swards (see for instance, Schirmel et al. 2010), which together with Coleoptera are described as the major groups in the diet of the little bustard (Jiguet 2002). In the laboratory, arthropods were mostly classified to order level, but Coleoptera, Orthoptera, Hemiptera and Hymenoptera were classified to family level, following the taxonomic classification of Bisby et al. (2007).

Data analyses

Statistical analyses were accomplished in three steps. First, we used univariate analysis of variance (ANOVA) to identify plant and arthropod variables that were significantly related with both male and female occurrence sites. Rare plant species (i.e. occurring in less than 10 sampling sites) were excluded from the analyses. Arthropod variables included each *taxon* abundance and the total abundance of arthropods. Insect abundance and floristic richness were log-transformed to normalize data and minimize the influence of extreme values.

Secondly, a principal component analysis (PCA) was used to search for different typologies of association between the variables presenting significant results in ANOVA analysis. Both random and presence sites were used when implementing this approach. We preferred this option instead using all variables in the PCA because we found a strong variation in data. This strong variation is justified by the larger number of vegetation communities and ecotypes present at sampling sites, which makes PCA components hardly interpretable.

Finally, aiming to obtain explanative models linking little bustard sites, arthropod and plant composition variables, generalized linear models (GLM, McCullagh and Nelder 1989) were computed using the presence/absence of little bustard as dependent variable and PCA components as explanatory variables (i.e. the scores of each principal component).

Only components with eigenvalues over one entered the GLM modelling procedure (Zuur et al. 2007). A binomial error and a logit link-function were assumed for GLMs. Saturated models were previously inspected for

overdispersion then, a model averaging procedure on all possible R models was performed following Burnham and Anderson (2002). Therefore, we obtained Akaike's information criterion corrected for small sample size (AIC_c), and in order to compare models we calculated Akaike weights as follows:

$$w_i = \frac{\exp\left(-\frac{1}{2}\Delta_i\right)}{\sum_{1}^{R}\exp\left(-\frac{1}{2}\Delta_r\right)}, \qquad \text{where} \quad \Delta_i = AIC_i - AIC_{\min}$$

Model averaging was performed using a 95% confidence set of Akaike weights, thus obtaining the selection probability of each variable. As highlighted by Burnham and Anderson (2002) a problem in estimating Akaike weights for individual variables is that poor predictors are not expected to have selection probabilities close to zero. To overcome this, we followed the same approach defined by Whittingham et al. (2005) which consists in adding a single randomly generated predictor that was uncorrelated with the response variable to the existing data set of real variables. The selection probability for the randomly derived predictor (null mean and null interval) was obtained by performing 100 simulations. We tested the residuals of GLM averaged models for spatial autocorrelation through Moran's I statistic (Cliff and Ord 1981). We did this because little bustard distribution (notably the distribution of males) and plant distribution can potentially present a spatially aggregated pattern, conducting to eventual problems of spatial autocorrelation (see for instance Fleishman and Nally 2006). Plant distribution in particular, depend on soil properties and water availability, which are not randomly distributed and can be quite different between the grassland patches of our study area (west patches are frequently more humid and present better soils). If significant autocorrelation values were found in the residuals of averaged models, we dropped GLM modelling and

repeated model averaging procedure, using generalized linear mixed models (GLMM, Bolker et al. 2009) entering as random factor a variable representing the six grassland patches where the surveys were conducted.

The fit of models was evaluated using the Area Under the Curve (AUC) generated by the Receiver Operating Characteristic (ROC; Pearce and Ferrier, 2000). AUC values over 0.80 indicate good model performance (Fielding and Bell, 1997). All calculations were performed using R for Windows (R Development Core Team, 2007).

RESULTS

Floristic abundance and richness

Plant taxonomic composition of sampling sites included 224 species from 42 plant families. Representative *taxa* included 81 species in the male dataset (17 families) and 63 species in the female dataset (15 families).

Univariate ANOVA analyses indicate that both male and female occurrence sites are located in sites with high floristic richness (Table 1). Fabaceae species are those presenting the most significant values in male dataset, notably *Trifolium striatum*, *Ornithopus compressus* and *Trifolium cherleri*. Gramineae species were also well represented in male territories, particularly *Taeniatherum caput-medusae* and *Cynodon dactylon*. Conversely, species such as *Avena sativa*, *Dactylis glomerata* and *Vulpia bromoides* were negatively associated with male territories.

Table 1 - Comparison of mean plant species abundance, clover cover and floristic richness at breeding female, territorial male and random sites. Statistical significance for the difference of the means was tested using univariate analysis of variance (ANOVA). Only variables significant at female or male datasets are presented. Statistically significant values are presented in bold. Plant families are presented in brackets as follows: A - Asteraceae, F - Fabaceae, J – Juncaceae, P – Poaceae and Po - Polygonaceae

	Female dataset						**Male dataset**					
	Random sites		Female sites				Random sites		Male sites			
Species	Mean	SD	Mean	SD	F	P-value	Mean	SD	Mean	SD	F	P-value
Avena barbata (P)	0.95	1.32	1.55	1.58	4.85	**0.030**	0.65	1.14	0.91	1.27	2.13	0.147
Avena sativa (P)	-	-	-	-	-	-	0.58	1.24	0.03	0.18	17.82	**<0.001**
Carlina racemosa (A)	1.02	1.41	1.51	1.67	2.95	0.089	0.73	1.16	1.33	1.51	8.77	**0.003**
Chamaemelum fuscatum (A)	0.18	0.69	0.15	0.46	0.06	0.812	0.02	0.15	0.13	0.42	4.81	**0.030**
Cynodon dactylon (P)	1.35	1.46	1.77	1.67	2.06	0.154	1.30	1.45	1.86	1.63	5.84	**0.017**
Dactylis glomerata (P)	0.42	0.84	0.57	1.20	0.59	0.445	0.91	1.24	0.39	0.71	12.05	**<0.001**
Gaudinia fragilis (P)	0.65	1.31	1.23	1.50	4.93	**0.028**	0.87	1.44	0.81	1.40	0.10	0.757
Hypochaeris glabra (A)	0.16	0.55	0.34	0.98	1.50	0.223	0.38	0.86	0.71	1.16	4.53	**0.035**
Juncus capitatus (J)	0.44	0.93	0.47	1.05	0.04	0.845	0.10	0.43	0.29	0.73	4.18	**0.042**
Lotus subbiflorus (F)	0.84	1.15	0.58	1.17	1.38	0.243	0.59	1.10	1.01	1.36	5.08	**0.025**
Medicago polymorpha (F)	0.08	0.33	0.51	1.09	8.75	**0.004**	0.29	0.78	0.31	0.78	0.03	0.857
Micropyrum tenellum (P)	0.47	1.00	0.32	0.96	0.64	0.425	0.47	0.98	0.83	1.35	4.19	**0.042**
Ornithopus compressus (F)	0.66	1.24	1.13	1.30	3.93	**0.050**	0.30	0.75	0.72	1.03	9.54	**0.002**
Phalaris aquatica (P)	-	-	-	-	-	-	0.19	0.64	0.02	0.15	5.79	**0.017**
Rumex bucephalophorus (Po)	0.16	0.49	0.62	1.04	9.70	**0.002**	0.28	0.64	0.38	0.83	0.755	0.386
Scorpiurus vermiculatus (F)	0.27	0.73	0.79	1.17	8.42	**0.004**	0.34	0.61	0.49	0.96	1.68	0.196
Taeniatherum caput-medusae (P)	0.21	0.77	0.15	0.46	0.24	0.628	0.28	0.79	0.74	1.29	8.18	**0.005**
Trifolium cherleri (F)	0.53	1.08	0.57	1.14	0.03	0.871	0.31	0.67	0.70	1.16	7.23	**0.008**
Trifolium glomeratum (F)	1.27	1.50	1.34	1.58	0.05	0.820	0.77	1.24	1.23	1.34	5.62	**0.019**
Trifolium scabrum(F)	0.11	0.41	0.38	0.84	4.84	**0.030**	-	-	-	-	-	-
Trifolium striatum(F)	-	-	-	-	-	**-**	0.03	0.18	0.42	0.83	17.84	**<0.001**
Trifolium subterraneum (F)	0.10	0.35	0.32	0.73	4.63	**0.033**	0.16	0.43	0.09	0.35	1.72	0.191
Vulpia bromoides (P)	-	-	-	-	-	-	0.27	0.66	0.09	0.41	4.99	**0.027**
Floristic richness	19.68	6.27	23.34	6.22	9.82	**0.002**	19.21	6.21	21.01	5.04	6.12	**0.014**

Fabaceae were clearly dominant in female sites. From the eight species presenting significant results in the ANOVA analyses, five were from Fabaceae, namely *Medicago polimorpha*, *Scorpiurus vermiculatus, Trifolium scabrum*, *T. subterraneum* and *Ornithopus compressus*. *Avena barbata*, *Rumex bucephalophorus and Gaudinia fragilis* were also significantly associated to female sites. A comparison of ANOVA significant results between male and female sites is presented in Table 1.

Arthropod abundance

A total of 38185 arthropods were captured. The dominant *taxa* were Hemiptera (42%), Orthoptera (17%), Diptera (14%) and Coleoptera (13%).

Abundance of Acrididae and Formicidae (i.e. the number of individuals) was significantly higher both at male and female sites, than at random sites (Table 2). The abundance of Tettigonidae was also higher at male sites but not at female sites. Conversely, total abundance of arthropod was higher at female sites than at random sites, but not at male sites. Additionally, female sites present significantly higher abundances of Coleoptera than random sites, namely Cleridae, Curculionidae, Chrysomelidae, Oedemeridae and Malachiidae.

Concerning Hemiptera group, Reduviidae abundance was found to be higher at female than at random sites. Conversely, Lygaeidae and Delphacidae presented significantly lower abundances at male than at random sites. Arachnida, Lepidoptera and Diptera did not presented any type of association with little bustard sites. A comparison of ANOVA significant results between male and female sets is shown in Table 2.

Table 2 - Comparison of mean arthropod family abundance and total arthropod abundance at breeding female, territorial male and random sites. Statistical significance for the difference of the means was tested using univariate analysis of variance (ANOVA). Only arthropod abundances significant at female or male datasets are presented. Statistical significant values are presented in bold.

	Female dataset						Male dataset					
	Random sites		Female sites				Random sites		Male sites			
	Mean	SD	Mean	SD	F	P-value	Mean	SD	Mean	SD	F	P-value
Chrysomelidae	2.77	5.99	5.29	8.01	5.84	**0.017**	2.09	2.66	2.13	2.46	0.00	0.964
Cleridae	0.04	0.26	0.58	1.95	6.26	**0.014**	-	-	-	-	-	-
Malachiidae	0.04	0.26	0.25	0.87	4.33	**0.040**	0.29	0.66	0.19	0.38	0.94	0.353
Curculionidae	0.89	1.44	2.08	3.73	5.99	**0.016**	1.06	1.59	0.68	0.99	3.69	0.065
Oedemeridae	0.09	0.25	0.25	0.48	4.79	**0.031**	0.39	0.94	0.39	0.74	0.39	0.923
Reduviidae	0.02	0.19	1.31	5.53	6.78	**0.010**	-	-	-	-	-	-
Lygaeidae	12.81	45.04	11.14	33.09	0.01	0.913	1.64	7.34	0.15	0.43	11.28	**0.001**
Delphacidae	-	-	-	-	-	-	0.54	2.31	0.07	0.25	5.23	**0.025**
Formicidae	2.58	4.36	4.79	8.65	5.47	**0.021**	3.10	4.91	5.01	8.06	4.27	**0.032**
Acrididae	6.44	8.15	10.18	8.63	13.11	**<0.001**	5.93	7.71	10.63	11.77	12.41	**<0.001**
Tettigoniidae	1.98	2.57	2.63	2.78	1.92	0.169	3.09	5.33	3.90	4.00	4.80	**0.027**
Arthropod abundance	60.52	72.27	85.39	109.16	5.17	**0.025**	68.76	54.02	65.68	35.67	0.10	0.740

Linking plant, arthropod and the little bustard

The number of variables entering PCA analysis was 22 in the male dataset (see statistical procedures for details on variable selection). Seven components with eigenvalues greater than one were obtained, representing 59.18% of the total variance explained (Table 3). As expected, our first attempt to model male response to vegetation/arthropod typologies using GLM returned significant levels of autocorrelation in the residuals of the averaged model. The use of GLMM using the grassland patch as a random factor allowed us to overcome this problem. The averaged male model obtained by means of this GLMM approach was identical to the autocorrelated GLM model, although spatial

autocorrelation was no longer found in the residuals (Moran I statistic= 0.034, p-value = 0.363, n.s.). According to this model, components 1, 3, 4 and 6 were those presenting higher selection probabilities (Table 4). The remaining components showed low to moderate selection probabilities. The averaged GLMM model shows a good accuracy presenting an AUC of 0.846. Moreover, all models with $\Delta AIC \leq 4$ units presented an AUC above 0.84, which also indicates a god fit for the modelling approach. PCA components 1 and 4 present the highest selection probabilities in the averaged model (Table 4). According to component 1, male territories are positively related with floristic species richness and with *Trifolium species* (*T. cherleri*, *T. glomeratum, T. striatum*) and *Carlina racemosa* abundances, but also with Acrididae and Tettigonidae abundances. Conversely, male territories are negatively associated with *Avena sativa* abundance, typical of cereal crops and improved pastures for mowing. Component 4 is negatively linked with male displaying sites contrasting locations with high abundance of dense/tall Gramineae vegetation of *Phalaris aquatica, Dactylis glomerata* and *Vulpia bromoides*, where insects of families Lygaeidae and Tettigonidae are also abundant and sites with low abundances of *Cynodon dactylon*, *Chamaemelum fuscatum*, *Juncus capitatus*. These three species are often associated with wet depressions in which water is retained in the soil for longer than elsewhere. Component 3 is negatively linked with males displaying sites defining sites in a general way poorly correlated to arthropods. This component contrasts mostly locations with high abundance of dense Graminea vegetation of *Cynodon dactylon*, *Dactylis glomerata* and *Avena sativa*, which are typical of improved pastures for mowing or cereal crops and locations with low abundances of short

vegetation of *Lotus subbiflorus*, *Ornithopus compressus* and *Juncus capitatus* from temporarily flooded pastures. Lastly, component 6 is also negatively linked with male displaying sites contrasting higher abundances of *Juncus capitatus*, *Chamaemelum fuscatum*, *Dactylis glomerata* and of Lygaeidae, with low abundances of *Ornithopus compressus*.

Table 3 - Summary results for principal component analysis (PCA) on arthropod abundance and plant composition variables (see text for variable selection procedures) of little bustard territorial male dataset. Only components with eigenvalues over one are presented. Correlation values below 0.2 in absolute value were omitted.

Component	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Eigenvalue	3.12	2.66	2.06	1.67	1.23	1.18	1.10
Cumulative % of variance	14.20	26.30	35.68	43.25	48.83	54.20	59.18
Loadings							
Floristic richness	0.64			0.24	0.31	0.22	
Avena sativa	-0.43		0.37				-0.34
Taeniatherum caput-medusae	0.20	0.64	-0.34	-0.24			
Ornithopus compressus	0.29	-0.23	-0.40		0.31	-0.35	
Hypochaeris glabra	0.33	0.61					
Trifolium striatum	0.36		0.23		0.46		
Carlina racemosa	0.43	0.50				-0.25	
Trifolium glomeratum	0.56	-0.50					
Trifolium cherleri	0.59	-0.32				0.31	
Chamaemelum fuscatum		-0.31		-0.38		0.54	
Cynodon dactylon			0.57	-0.40			
Dactylis glomerata		0.35	0.51	0.29			
Juncus capitatus		0.46	-0.41	-0.30		0.36	
Lotus subbiflorus			-0.65				
Micropyrum tenellum		0.79	-0.20				
Phalaris aquatica				0.34	0.26	0.25	-0.61
Vulpia bromoides			-0.21	0.49	-0.46		0.39
Lygaeidae				0.51	0.37	0.38	
Delphacidae	-0.25		0.28		0.27		0.50
Formicidae	0.44	0.23		0.23	-0.40		
Tettigoniidae	0.61	0.21		0.45			
Acrididae	0.72		0.26				

Table 4 - Summary results for averaged GLMM model on little bustard territorial male dataset. The table shows the variables (principal components) included in each model, the AICc, ΔAICc, Akaike weights, the model selection probability and the regression coefficient values (β) along with standard error (SE). The AUC statistic reflects the model fit for each model and for the averaged model (returned from averaged coefficient values). The models shown are within ΔAICc < 4. The null interval represents the selection probability for a randomly derived predictor (see text for details).

Model	PC1	PC2	PC3	PC4	PC5	PC6	PC7	AICc	ΔAICc	Weight	AUC
1	•	•	•	•		•		181.64	0	0.30	0.846
2	•		•	•		•		182.3	0.66	0.22	0.841
3	•	•	•	•	•	•		183.81	2.17	0.10	0.846
4	•	•	•	•		•	•	183.83	2.19	0.10	0.847
5	•		•	•	•	•		184.38	2.74	0.08	0.843
6	•		•	•		•	•	184.43	2.79	0.08	0.841
β	0.86	0.12	-0.40	-0.84	0.01	-0.61	0.01		Model averaged:		0.846
SE	0.15	0.14	0.17	0.19	0.10	0.24	0.13				
Selection probability	1.00	0.57	0.96	1.00	0.24	0.98	0.24		Null mean: 0.33 Null interval: 0.24-0.84		

The number of variables entering de PCA analysis was 18 in the female dataset. Six components with eigenvalues greater than one were obtained, which represented 64.80% of total variance explained (Table 5). The averaged female model obtained by means of GLM modelling on these six components, revealed no autocorrelation in the residuals (Moran I statistic =0.028; p-value = 0.50, n.s.). According to this model, components 1, 2, 4 were those presenting higher selection probabilities (Table 6). The remaining components obtained low to moderate selection probabilities. The averaged GLM model shows a good accuracy presenting an AUC of 0.803. Moreover, all models with ΔAIC≤ 2

units present an AUC above 0.80, which also indicates a god fit for the modelling approach.

Table 5 - Summary results for principal component analysis (PCA) on arthropod abundance and plant composition variables (see text for variable selection procedures) of little bustard breeding female dataset. Only components with eigenvalues over one are presented. Correlation values below 0.2 in absolute value were omitted.

	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalues	3.87	2.20	1.67	1.62	1.20	1.11
Cumulative proportion of variance	21.48	33.68	42.97	51.99	58.65	64.80
Loadings						
Floristic richness	0.63	0.38	-0.31			
Avena barbata		0.44	-0.32	0.47		0.38
Gaudinia fragilis	0.62	0.22	-0.41	-0.33		
Medicago polymorpha		0.42		0.32	-0.69	
Ornithopus compressus	0.66		-0.36	-0.26		
Rumex bucephalophorus	0.57		-0.24			
Scorpiurus vermiculatus		0.56		0.41		-0.55
Trifolium scabrum		0.45			0.65	
Trifolium subterraneum		0.60			0.36	
Chrysomelidae	0.65		0.36			-0.43
Curculionidae	0.77					
Reduviidae	0.45	-0.30	-0.20			
Cleridae	0.62	-0.37				
Malachiidae		0.38	0.64	-0.28		
Oedemeridae		0.44	0.48	-0.48		0.28
Formicidae			0.25	0.52		
Acrididae		-0.20		0.46		0.53
Arthropod Richness	0.66	-0.21	0.41	0.24		

Table 6 - Summary results for averaged GLM model on little bustard breeding female dataset. The table shows the variables (principal components) included in each model, the AICc, ΔAICc, Akaike weights, the model selection probability and the regression coefficient values (β) along with adjusted standard error (Adj. SE). The models shown are within ΔAICc < 4. The AUC statistic reflects the model fit for each model and for the averaged model (returned from averaged coefficient values). The null interval represents the selection probability for a randomly derived predictor (see text for details).

Model	PC1	PC2	PC3	PC4	PC5	PC6	AICc	ΔAICc	Weight	AUC
1	•	•		•			131.44	0.00	0.26	0.801
2	•	•		•		•	132.24	0.80	0.18	0.806
3	•	•	•	•			133.17	1.73	0.11	0.801
4	•	•		•	•		133.44	2.00	0.10	0.802
5	•	•	•	•		•	133.85	2.41	0.08	0.806
6	•	•		•	•	•	134.37	2.93	0.06	0.805
7	•	•	•	•	•		135.21	3.77	0.04	0.802
8	•	•					135.43	3.99	0.04	0.769
β	0.55	0.44	0.04	0.38	-0.02	-0.10	Model averaged:			0.803
Adj. SE	0.22	0.14	0.19	0.12	0.22	0.12				
Selection probability	1.00	0.97	0.29	0.88	0.24	0.40	Null mean: 0.33 Null interval: 0.23-0.71			

Component 1 is by far the most important for breeding females enhancing the importance of floristic species richness, total arthropod abundance and several Families of Coleoptera (see Table 4). Plant species with high correlation values were *Ornithopus compressus, Gaudinia fragilis* and *Rumex bucephalophorus*. Component 2 is mostly related with Fabaceae species (*Trifolium* spp. and *Scorpiurus vermiculatus*) and with Coleoptera of Oedemeridae and Malachiidae Families. Component 4 relates mostly to locations with high abundance on Acrididae and Formicidae, and with low

abundances of Coleoptera; plant composition relates mainly to *Avena barbata*, *Scorpiurus vermiculatus* and *Medicago polymorpha*.

DISCUSSION

This work highlights the complementary role of plant and arthropod composition and abundance in breeding little bustard microhabitat selection in Iberian pasture dominated areas agricultural landscapes. Higher floristic richness and Fabaceae abundance are likely to enable higher abundance of arthropod, in particular Coleoptera and Orthoptera which are known to be essential for the species breeding performance (Jiguet et al. 2002; Traba et al. 2008). Both for males and females, the first PCA component seems to define the optimal interaction between plant and arthropod. The remaining PCA components identified in the averaged models seem to reflect “alternative habitats”, whose use by little bustards may be related not only with the experience and social status of each individual, but also with the availability of fields with high plant and arthropod richness and abundance. For territorial males, the existence of sites with high abundance of *Ornithopus compressus* seems to be an interesting alternative to highly diverse sites (see the loadings of components 3, 4 and 6 for this species in Table 3). For breeding females these alternatives are exclusively sites dominated by Fabacea species. Nonetheless, it should be noted that under adequate field management most of these vegetation typologies may coexist, both within male territories and within chick rearing areas. In some cases, the presence of females in these alternative habitats may be explained by some loss of pasture quality throughout the breeding season resulting from changes on grazing pressure once females

established to nest and therefore can hardly move (contrarily to males) to another field during the incubation and in the first days after hatching.

Based on the typologies which obtained higher selection probabilities in model averaging procedure, plant composition differs considerably from male to female sites, reflecting contrasting behaviours and consequently different breeding requirements. This finding is consistent with the results on sexual segregation based on vegetation structure shown by Morales et al. (2008). The prevalence of Fabaceae species (i.e. the ratio between the number of Fabacea species and the number of species of other plant families) in female typologies with higher selection probabilities seems to be higher than the prevalence of Fabacea species in male typologies. On the other hand, male sites are related with a higher variety of plant species, notably of Asteraceae. Also, little bustards seem to actively search sites abundant in some particular clover species, some of them showing relatively low prevalence in pastures (Table 3). This active search pattern gains further evidence if we consider that non-significant results were obtained for clover cover, both at male and female sites. The importance of legume crops for steppe-birds has been described in several studies (Jiguet et al. 2002; Lane et al. 1999; Ursúa et al. 2005). For the little bustard in particular, the availability of alfalfa (*Medicago sativa*) fields in cultivated areas was pointed as one of major factors influencing the breeding ecology of the species (Bretagnolle et al. 2010; Jiguet et al. 2002; Salamolard and Moreau 1999). It should be noted that an important number of Fabaceae species identified at female sites are characteristic of productive grassland habitats which are also protected under the European Habitat Directive (*Pseudo-steppe with grasses and annuals of Thero-Brachypodietea – 6220, subtype 2, Poetalia

bulbosae; San Miguel 2008). These communities seem to be fragmented and in poor state of preservation in our study area but could act as an important food resource for arthropods. Further research is needed on this subject.

Arthropods seem to be more important for females than for males, which is an expected result since males do not take part in chick-rearing. Nonetheless and contrasting with Jiguet et al. (2002), potential resource defence by males is supported based on the abundance of Acrididae and Formicidae at the selected sites (see also Traba et al. 2008). Furthermore, we cannot exclude that high total arthropod abundance or vegetation composition similar to that of female sites could also be found at locations distant to displaying sites but still inside male territories, since: (1) arthropod and vegetation communities can vary strongly within fields; and (2) female sites are relatively close to male displaying sites (mean distance=246±148m).

Wolff et al. (2002) already hightlighted the importance of “improved pastures” for the Little bustard in southeast France. However, functional mechanisms on the basis of this relationship were not fully described in that study. The findings of our study point out that plant composition may be in the basis of the preference for a given type of improved pasture, by ensuring higher arthropod abundance. The experimental work of Koricheva et al. (2000) pointed in the same direction, highlighting the importance of plant species composition and the presence of legumes in plant mixtures for the manipulation of arthropod abundance. We should note that in practice, some of the plant species identified in this study are already used in our study area in seed mixtures for pasture improvement (Olea 1991; Salgueiro 2002). Some of these species are of great interest for the little bustard, particularly *Trifolium subterraneum, Ornithopus*

compressus and *Medicago polymorpha*, while others do not seem interesting at all (i.e. *Dactylis glomerata*, *Avena sativa* or *Phalaris aquatica)*. Therefore, the species composition of pastures used by little bustards (and other steppe birds) may potentially become a relevant element of their management. The information on plant species composition requirements at breeding sites can complement the existing information based on vegetation structure (see for instance, Morales et al. 2008; Silva et al. 2001), allowing to go further in identifying the most favourable seed mixtures for pasture improvement, thereby increasing arthropod availability, which is a key factor to improve the breeding success of little bustards and other threatened steppe birds.

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4. THE IMPORTANCE OF GRAZING REGIME IN THE PROVISION OF BREEDING HABITAT FOR GRASSLAND BIRDS: THE CASE OF THE ENDANGERED LITTLE BUSTARD (*Tetrax tetrax*)

ABSTRACT

In Mediterranean dry grasslands, grazing by domestic animals is an important agricultural activity on dry grasslands. Several bird species occur in these grazed habitats and are now experiencing a nearly continuous decline. We investigated the impact of livestock grazing on the threatened little bustard (*Tetrax tetrax* L.). The study was conducted at the NATURA 2000 Site/Important Bird Area of Cabrela, Portugal. Our main goals were to investigate responses of little bustard territorial males and breeding females to different livestock management practices, namely pasture types, stocking rates and sward structure. Bird distribution was surveyed using car and foot surveys. Data on grazing was supplied by land managers every 10 days from February to June through field interviews. Generalized additive models and model averaging were used to compute predictive models. Results indicate that higher probabilities of occurrence were found in long-term pastures and under light-moderate grazing conditions (stocking rates around 0.4 LU/ha). Conversely, lower probabilities of occurrence were found in ungrazed or heavy grazed fields. Males occurred mostly in large fields, but this variable seemed to be less important for females. On the other hand, green plant cover and the vegetation height were good predictors for the occurrence of females but not for males. Females used mostly pastures with vegetation height around 20-25 cm. Our results suggest that grazing management plans that aim to conserve little bustard populations should consider (1) the maintenance of the larger long-term pastures and (2) the use of light-moderate stocking rates (0.2-0.6 LU/ha).

KEYWORDS

Tetrax tetrax; stocking rates; livestock; pasture management; vegetation structure; green plants.

INTRODUCTION

In Europe 173 bird species with an unfavourable conservation status occur in grassland habitats (Tucker and Dixon, 1997). Most of these taxa are resident species associated with Mediterranean pseudosteppes (Suárez et al., 1997) and sparse pastoral of *Quercus suber* (L.) and/or *Q. rotundifolia* (Lam.) forested areas, hereafter referred broadly as dry grasslands. Several of these species are experiencing a nearly continuous decline and are now classified as threatened or near-threatened (e.g. the great bustard *Otis tarda* L., the lesser kestrel *Falco naumanni* Fleischer and the little bustard *Tetrax tetrax* L.) at different geographic levels (BirdLife International, 2008; Cabral et al., 2006; Madroño et al., 2004; Rocamora and Berthelot, 1999).

Originating mostly from human depletion of pristine Mediterranean forests (Blondel and Aronson, 1999; Suárez et al., 1997; Tucker and Dixon 1997), these anthropogenic habitats have been managed historically for extensive livestock grazing and cereal crop farming in a traditional low-intensity rotating system (Donázar et al., 1997; Gómez-Limón and Fernandez, 1999). However, in the last decades an increase in livestock numbers has occurred, partly induced by the European Common Agricultural Policy (CAP) of the European Union (EU), through financial incentives to farmers (Donázar et al., 1997; Suárez et al., 1997). On the other hand, scientific advances on dairy science and rangeland management allowed for the increase of livestock densities in pastures and the use of new grazing areas formerly considered poor or unsuitable for livestock.

Increased livestock and crop yields led to an intensification of agricultural landscapes and a loss of biodiversity (Aich and Waterhouse, 1999; Donald et al., 2002; Geigen et al., 2010; Potts, 1997). Presently, overgrazing represents the fourth most important threat to grassland habitats and their associated bird species, after crop intensification, pesticide use and land abandonment (Tucker and Dixon, 1997). Cattle numbers increased 36% between 1970 and 2003 in French Mediterranean regions (AGRESTE, 2005) and 95% between 1989 and 2009 in Portuguese regions where the most important dry grasslands are located (INE, 2011). In Spain, grazing systems became more intensive from 1970 onwards because of the increase in the number of animals in pastures (e.g. 35% in cattle numbers since 1984; EUROSTAT, 2005), but also from supplementary feeding and fence building (Suárez et al., 1997).

The impacts of livestock grazing on wild birds are still poorly documented and most studies have been limited to describing grazing intensity on an ordinal scale (e.g. ungrazed, lightly grazed…) with no assumptions about the local or regional representativeness (Bock and Bock, 1999; Martin and Possingham, 2005; Wilkins and Swank 1992). These impacts are described as both direct, through trampling, disturbance of nests and resting areas or food competition (Vickery et al., 2001) and indirect, by modifying vegetation and soil parameters or changing the dynamic of vegetation communities (Adler et al., 2001; Hobbs, 1996; Kruess and Tscharntke, 2002).

We investigated the importance of livestock grazing on the threatened avifauna of Mediterranean dry grasslands, using the little bustard *Tetrax tetrax* as a study case. This grassland species is experiencing a dramatic decline in range and numbers, apparently connected with habitat loss through

modifications in land-use and agricultural intensification (e.g. De Juana, 2009; García et al., 2007; Wolff et al., 2001). Our main goals were: (1) to evaluate the response of territorial males and breeding females to livestock handling practices and to pasture characteristics, particularly in terms of sward structure during the nesting and chick-rearing periods; (2) to produce predictive models relating stocking rates with the occurrence of territorial males and breeding females; and (3) to propose optimum stocking practices for the management of little bustard breeding populations.

MATERIALS AND METHODS

Study Area

The study area is located in the SW of Portugal (38°29'N, 8°20' W, 137 m a.s.l.) in the Mesomediterranean and Termomediterranean biogeographic regions (Rivas-Martinez et al., 2004). The area is included in the NATURA 2000 national list of sites (Site of Community Importance of Cabrela, hereafter SCI of Cabrela) and in the European list of Important Bird Areas (Cabrela IBA; Costa et al., 2003). Climate shows both ocean and continental influences, shifting from sub-humid to dry. Average annual temperatures vary from 15.6 to 16.3 º C and annual rainfall between 574 and 708 mm (SNIRH, 2007). The study area is part of a mosaic landscape dominated by *Quercus suber* (L.) and/or *Q. rotundifolia* (Lam.) forested areas, grasslands and river valleys. Soils are mostly acidic and with diverse levels of fertility (IA, 1980; IDRhA, 1982).

The study area has a surface of 6276 ha, equivalent to 50-60% of the SCI/IBA of Cabrela grassland area, which is ca.10-11% of the total area of SCI/IBA of Cabrela. Most important land uses are traditional rotation cereal crops and livestock grazing (mostly cattle). Pastures occupy ca. 40-50% of the area (55-65% considering pastures growing in the understory of sparsely forested areas), whereas irrigated lands occupy less than 5% of total area. Other land uses include cereal fields (10-25%), improved pastures (5%), dense forests (5%) and shrublands (5%). According to our own data, the average and highest daily livestock stocking rates during our study were respectively 0.35 and 5.57 Livestock Units (LU) per hectare. Stocking rates increased about 58% in this region between 1989 and 2009 (INE, 2011). Pasture fertilization is uncommon in the area.

Field Techniques

Surveys of little bustard territorial males were conducted twice during the month of May of 2003 and 2004. This period was selected because previous studies conducted in the area have shown that male breeding numbers are highest at this time (Faria and Rabaça, 2004). For the purpose of this study we only used data from the second visits (19-25 of May of 2003 and 17-24 of May of 2004), which corresponded to the peak of male displaying activity. The land surface covered in each period was 4041 ha in the first year and 4653 ha in the second. The spatial distribution of males was assessed using the methodology adopted by Leitão and Costa (2001) and Wolff et al. (2001). Since little bustard densities are low in the study area, we used surveys on a 4x4 vehicle to map male displaying sites (exceptionally, a few areas with hard tracks were surveyed

on foot). Surveys were carried out during the first three and a half hours after sunrise, with stops every 500 meters and/or on the top of the hills for searching with binoculars or spotting scope. The dataset for males dataset consists of 124 sampling sites: 67 territorial male displaying sites and 57 random sites (absence data). Displaying sites are expected to be a good indicator of grassland use since males are highly conspicuous when displaying. On the other hand, their location was mostly coincident in the two surveys performed during May. The spatial arrangement of random sites was generated automatically in GIS software (ArcMap). In this procedure, the minimum distance between adjacent random/displaying sites was set to 350 meters in order to minimize potential problems of spatial autocorrelation.

Female surveys were conducted in 2003, 2004 and 2006, during nesting and chick rearing periods, from the last week of April to the end of June. The land surface covered in each year was: 898 ha in 2003, 1468 ha in 2004 and 1590 ha in 2006. Contrarily to males, females are very hard to locate during this period. Spatial distribution of females was assessed using a similar methodology adopted by Wolff et al. (2002). Fields were surveyed by 2-3 experienced observers walking 50 m apart from each other and searching regularly for walking or flushed females. Differentiation between adult female and juvenile males was made based on account bird morphological traits and behaviour (see Jiguet and Wolff, 2000). Flushed females were carefully followed in order to minimize potential double counts. Surveys were carried out during the first 3-4 hours after sunrise and 2-3 hours before sunset. The dataset of females comprises 102 sampling sites: 49 female sites and 53 random sites. The location of females is also likely to be a good indicator of grassland use,

due to low mobility of females during incubation and early chick rearing period, as supported by radiotracked females (N. Faria, unp. data). The spatial arrangement of random sites was generated automatically in GIS software (ArcMap). In this procedure, the minimum distance between adjacent random/displaying sites was set to 350 meters in order to minimize potential problems of spatial autocorrelation.

Digital aerial photographs (scale 1:5000; flight years 1995 and 2003) were analysed in order to define boundaries of fields. When necessary, this task was complemented by field observations. For the purpose of this study, only little bustards located on grazed fields or in fields with potential for grazing (i.e. ungrazed areas kept for cutting or for summer grazing) were considered. We made this decision because in our study area all females and more than 90% of male territories were found in these habitats. Therefore, locations on ploughed lands, summer crops and cereal fields were not considered.

Land managers (landowners or shepherds) were interviewed at the field every 10 days from February to June. In these visits, we asked for (1) the type of livestock present in a given field (cattle and/or sheep), (2) the stocking numbers and (3) the extent of the period of grazing in each field (number of days). This information allowed us to characterize the type of livestock rotation and the stocking rates in terms of Livestock Units (LU) per hectare. Stocking rates were calculated according to the following ratio: adult bovine = 1 LU; yearling bovine (aged 6-24 months) = 0.6 LU and adult sheep = 0.15 LU (IDRhA 2004). Information on stocking rates for male dataset comprise the 90 days prior to male surveys. For the female dataset, given the temporal dispersion of sampling, stocking rates refer to 15 March to 31 May period.

The information on vegetation structure variables was obtained at each sampling site, from nine sampling replicates: a central replicate and eight peripheral replicates, positioned according to the four main cardinal points. The first four replicates distanced ten meters from the central replicate, and the other four were twenty meters distant. Table 1 shows detailed information of all variables considered for this study.

Table 1 - Variables used to describe vegetation structure, grazing and pasture features.

Variable	Description	Type
SRat	Stocking rate expressed in livestock units per hectare (LU/ha). Reference period for territorial males: 90 days before the territorial male survey. Reference period for breeding females: 15 March to 31 May (see text for details).	Additive
LivR	Type of grazing handling. Three types were considered: *CT* – Continuous grazing or short-term rotational grazing. Livestock grazes always the same field or is handled under a rotation system where each field is grazed less than 10 consecutive days; *MT* - Medium-term rotational grazing. Each field in the rotation system is grazed between 10 and 30 consecutive days; *LT* - Long-term rotational grazing. Each field in the rotation system is grazed more than 30 consecutive days.	Factor
VegH	Mean height of the vegetation. Measured at nine sample replicates.	Additive
VegC	Percent of cover. Estimated from nine sample replicates.	Continuous
PastL	Percent of long-term pasture within a 100m radius around male/female site. Long-term pastures are those used for grazing at least for two breeding seasons and with less than 5% of tree cover.	Continuous
GreenP	Percent of cover of green plant.	Continuous
FieldA	Size of the field (ha) where male/female was found.	Continuous

Statistical Analyses

Generalized additive modelling (GAM; Wood, 2009) was used to establish relationships between male/female sites and grazing/vegetation variables. GAMs were performed assuming a binomial error and a logit link-function. Candidate variables entering the multivariate models were previously inspected for collinearity and no Pearson correlation coefficients higher than 0.6 were found between those included in the calculations. Continuous variables were square-root and percentages arcsine transformed to minimize the influence of extreme values.

Saturated GAM models were previously inspected for overdispersion. An interaction term (linear) between green plant cover and livestock handling categories (see Table, for details on variables) was included in the saturated model of female dataset. This approach was not tested in the male dataset, because during displaying season the variability of green plant availability was low (vegetation was almost 100% green at this time). Then, model averaging on all possible R models was performed as defined by Burnham and Anderson (2002). First, we calculated Akaike's information criterion corrected for small sample size (AIC_c), then in order to compare models we calculated Akaike weights as follows:

$$w_i = \frac{\exp\left(-\frac{1}{2}\Delta_i\right)}{\sum_{1}^{R}\exp\left(-\frac{1}{2}\Delta_r\right)}, \qquad \text{where} \quad \Delta_i = AIC_i - AIC_{\min}$$

Model averaging was performed using a 95% confidence set of Akaike weights thus obtaining the selection probability of each variable. As highlighted

by Burnham and Anderson (2002), a problem in estimating Akaike weights for individual variables is that poor predictors are not expected to have selection probabilities close to zero. To overcome this, we followed the approach defined by Whittingham et al. (2005), which consists of adding a single randomly generated predictor that is uncorrelated with the response variable to the existing data set of real variables. The selection probability for the randomly derived predictor (null mean and null interval) was obtained by performing 100 simulations. The potential spatial correlation of data residuals of averaged models was assessed through Moran's I statistic (Cliff and Ord, 1981).

The fit of models was evaluated using the Area Under the Curve (AUC) generated by the Receiver Operating Characteristic (ROC; Pearce and Ferrier, 2000). AUC values over 0.80 indicate good model performance (Fielding and Bell, 1997). All calculations were performed using R for Windows (R Development Core Team, 2007).

RESULTS

Territorial Males

The density estimate of little bustard territorial males was 0.50 territorial males km^{-2}, locally reaching 2 territorial males km^{-2}.

The averaged additive model obtained indicated that pasture type, size of the field and stocking rates were the most important factors for the occurrence of territorial males (Table 2). The type of livestock rotation also presented a moderate-high selection probability. Vegetation cover, vegetation height and green plant cover seem to be poorly effective for modelling grassland use by

territorial males. The averaged model showed a good accuracy presenting an AUC of 0.87. Also, all models with $\Delta AIC \leq 4$ units presented an AUC above 0.84, reinforcing the robustness of model. Moran's I statistic indicated no significant spatial autocorrelation on the averaged model residuals (Moran's I statistic=0.007, p= 0.77, n.s.).

Male sites are positively associated with long-term pastures and with larger fields. The response of territorial males to stocking rate was clearly non-linear, assuming a quadratic shape (Figure 1). The simulations performed showed that the optimum stocking rates are found around 0.4 LU/ha, for both the averaged model and the best model (Figure 1). Both ungrazed areas and heavy grazed areas seem to be little used by territorial males. On the other hand, pastures under medium or long-term livestock rotation seem to be those preferred.

Breeding Females

The density of females was estimated at 0.25 breeding females km^{-2} for our study area. Female sites were mostly in the fields where territorial males were also found (89%) and which were close to displaying sites (mean distance to closest displaying site is 246±148m).

The averaged additive model obtained indicated that long-term pastures and the interaction between green plant cover and livestock rotation type are the most important factors for the occurrence of little bustard's breeding females (Table 3). The vegetation height and stocking rates were also good predictors of grassland use by breeding females. Livestock rotation, field size and vegetation cover present moderate-low selection probability.

Table 2 - Summary results for the averaged GAM model on territorial male data set. The table indicates the variables included in each model, the AICc, ΔAICc, Akaike weights, the model selection probability,the model fit (AUC statistic) and the regression coefficient values (β) along with adjusted standard error (Adj. SE). The models shown are within ΔAICc < 4.The null interval represents the selection probability for a randomly derived predictor (see text for details). The variables are presented as follows: additive variable - "*s(variable)*"; categorical variable - "*fac(variable)*.

Model	fac(LivR)		VegC	PastL	GreenP	s(SRat)		s(VegH)		FieldA	AICc	ΔAICc	Weight	AUC
1	•		•	•		•				•	129.5	0.00	0.174	0.871
2	•			•		•		•		•	130.2	0.63	0.127	0.869
3	•		•	•		•		•		•	130.6	1.08	0.101	0.870
4	•			•		•				•	130.8	1.25	0.093	0.862
5				•		•		•		•	131.4	1.88	0.068	0.849
6	•		•	•	•	•				•	131.6	2.04	0.062	0.873
7				•		•				•	131.7	2.15	0.059	0.841
8			•	•		•				•	132.1	2.62	0.047	0.847
9	•			•	•	•		•		•	132.5	2.95	0.040	0.869
10	•		•	•	•	•		•		•	132.7	3.14	0.036	0.872
11	•			•	•	•				•	132.9	3.39	0.032	0.864
12			•	•		•		•		•	133.0	3.45	0.031	0.850
β	LivR (MT)	LivR (LT)				SRat.1	SRat.2	VegH.1	VegH.2			Model averaged:		0.872
	1.28	0.95	-1.04	1.44	0.07	3.36	-0.56	8E-06	-0.19	0.30				
Adj. SE	1.09	0.84	1.44	0.41	0.70	1.33	0.41	0.01	0.30	0.11				
Selection probability	0.70		0.51	1.00	0.25	0.99		0.47		1.00		Null mean: 0.31 Null interval: 0.25-0.48		

The averaged model shows an AUC of 0.82 and all models with ΔAIC≤ 2 units present an AUC above 0.80, which still indicates a good fit for the model. Moran's I statistic indicated no significant spatial correlation on averaged model residuals (Moran's I statistic=-0.008, *p*=0.76, n.s.).

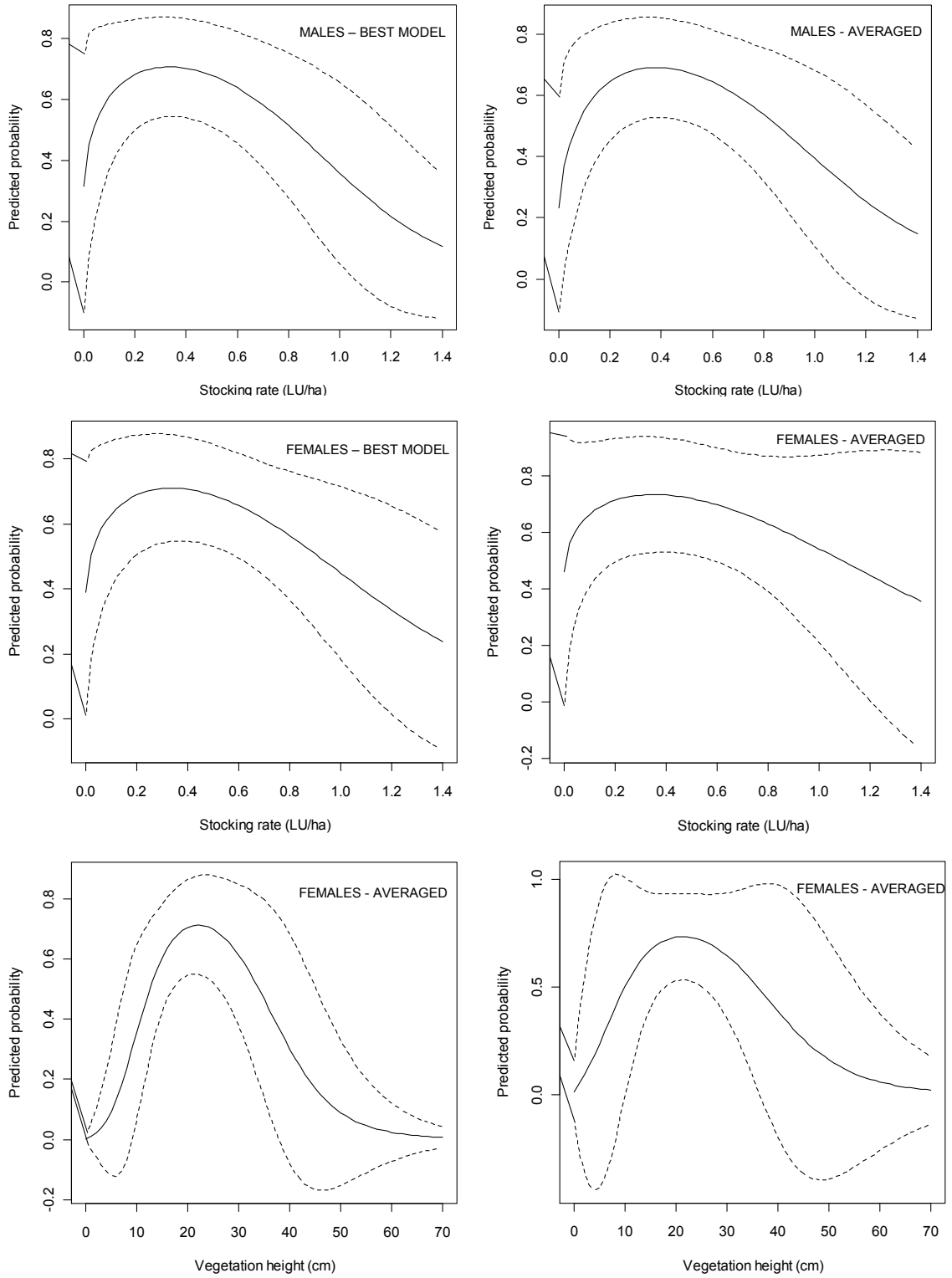

Fig. 1 - Simulated values for stocking rate (little bustard territorial males and breeding females) and vegetation height (breeding females only) resulting from averaged GAM model and best GAM model. The dotted lines represent two standard errors above and below the predicted values.

Female sites were also positively associated with long-term pastures. The green plant cover seems to be another important factor for the selection of breeding sites, particularly when handling livestock under long-term rotation. In contrast with territorial males, both sward height and stocking rate are helpful descriptors of female sward requirements. However, the selection probability of the variable stocking rate is lower than that observed for male averaged model. This is probably because stocking rates and vegetation height are in some extent correlated (Pearson's r=-0.35), which is an expected result, resulting in lower selection probability (but higher AICc) when both variables are included in a given model. The response of females to vegetation height and stocking rate is also non-linear, assuming a quadratic shape similar to that found for territorial males (Figure 1). The simulations performed showed that the optimum stocking rates for breeding females are found around 0.35-0.4 LU/ha and the optimal vegetation height was found between 20 and 25 cm. These results were similar for both the averaged model and the best model (Figure 1). Heavily grazed areas were also likely to be poor habitats for females, however stocking rates close to zero are predictably more attractive for females with nests or chicks than for males.

Table 3 - Summary results for the averaged GAM model on breeding female data set. The table indicates the variables included in each model, the AICc, ΔAICc, Akaike weights, the model selection probability, the model fit (AUC statistic) and the regression coefficient values (β) along with adjusted standard error (Adj. SE). The models shown are within ΔAICc < 4.The null interval represents the selection probability for a randomly derived predictor (see text for details). The variables are presented as follows: additive variable - "*s(variable)*"; categorical variable - "*fac(variable)*"; interaction between variables - *fac(variable):variable*.

Model	fac(LivR)	PastL	VegC	s(SRat)	s(VegH)	FieldA	fac(LivR):GreenP	AICc	ΔAICc	Weight	AUC
1		•		•	•		•	125.6	0.00	0.150	0.809
2	•	•		•		•	•	126.9	1.25	0.080	0.813
3	•	•		•	•	•	•	127.1	1.50	0.071	0.832
4	•	•		•	•		•	127.2	1.64	0.066	0.820
5		•		•	•	•	•	127.3	1.70	0.064	0.809
6		•	•	•	•		•	127.6	1.98	0.055	0.811
7		•			•		•	127.8	2.22	0.049	0.783
8	•	•			•	•	•	128.0	2.40	0.045	0.818
9	•	•		•			•	128.2	2.62	0.040	0.793
10		•			•	•	•	128.7	3.14	0.031	0.794
11	•	•			•		•	128.8	3.24	0.030	0.798
12	•	•	•	•	•		•	129.1	3.47	0.026	0.825
13		•		•			•	129.3	3.68	0.024	0.777
14	•	•	•	•		•	•	129.3	3.71	0.023	0.816
15		•	•		•		•	129.4	3.81	0.022	0.789
16		•	•	•	•	•	•	129.5	3.91	0.021	0.813
17	•	•	•	•	•	•	•	129.6	3.95	0.021	0.833

β	LivR (MT)	LivR (LT)			SRat. 1	SRat. 2	VegH. 1	VegH. 2		LivR (CT): GreenP	LivR (MT): GreenP	LivRot (LT): GreenP	Model averaged: 0.823
	0.80	-0.13	1.13	0.30	1.83	-0.24	2.38	-0.16	0.07	-1.29	0.52	4.31	
Adj. SE	1.14	0.83	0.44	0.97	1.42	0.35	1.77	0.34	0.11	1.63	1.17	1.89	
Selection probability	0.5		0.98	0.26	0.75		0.77		0.45	0.98			Null mean: 0.25 Null interval: 0.22-0.30

DISCUSSION

Occurrence of Little Bustard and Livestock Grazing Dynamics

Our study indicates that both little bustard males and females depend on light-moderately grazed areas for breeding with stocking rates around 0.4 LU/ha. Wolff et al. (2002) highlighted the importance of lightly grazed areas for nest success of the little bustard, in spite of having found a more or less similar female distribution in light and heavily grazed sites. Verdú et al. (2000) pointed out that controlled traditional grazing in Mediterranean pseudo-steppes is an important measure to favour vegetation and arthropod diversity. The selection of lightly grazed areas may suggest an access to high-quality habitats where vegetation structure and diversity hold up a diverse arthropod community including favourite and profitable arthropods for the species (see Jiguet, 2002 and Traba et al., 2008).

The results concerning the selection of pasture type are in general similar to those presented in other studies (Campos and Lopez, 1996; Silva et al., 2001; Wolff et al., 2002). We must emphasize that females use pastures with sparse tree cover more frequently than do males. These habitats could be important in providing concealment both for nesting and chick rearing when treeless long-term pastures with suitable swards are scarce. Furthermore, mowing is less frequently used and occurs later in the season in this habitat type, which can be highly advantageous for breeding females.

Livestock removal has been frequently associated with an increase in bird richness and abundance in grassland habitats (e.g. Bock and Bock, 1999; Krueper et al., 2003; Temple et al., 1999). We found no evidence of such an increase in abundance in the little bustard. Males typically display in vegetation

clear-cuts, which are scarce in ungrazed or residually grazed fields (i.e. fields were stocking rates are too low to alter vegetation structure). The few males settled in these areas were mostly found displaying along tracks or in pockets of skinny soils because vegetation is otherwise too high and dense to provide good displaying sites (see Morales et al. 2008, for a similar male preference in cereal croplands). On the other hand, ungrazed pastures present too dense vegetation for chick rearing, providing lower food accessibility/availability for chicks comparatively to grazed sites. However, it must be stressed that ungrazed areas could be important for nesting and chick rearing in dry years or in heavy grazed areas, where the availability of adequate swards is lower.

Heavy grazing seems to be problematic for both females and males. However, the presence of males in heavily grazed areas was not a rare event during fieldwork. This can be explained by male courtship behaviour (the need for clear-cuts). Also, in large sized fields under moderate-heavy grazing, livestock walk longer distances to feed but the frequency with which these distances are travelled is however strongly influenced by the access to drinking sites. Field observations indicate that such movement frequently enables the existence of small pockets of adequate vegetation structure in the areas farthest away from drinking sites. Heavy grazing is expected to affect mostly breeding performance, through trampling of nests, direct disturbance of incubation and exposure to predation due to livestock movements and removal of the vegetation.

Vegetation height was found to be a good descriptor of sward requirements for females but not for males. These results for females are also consistent with those found in cereal croplands by Morales et al. (2008). Male

displaying sites are frequently placed in areas presenting a different grassland structure than the one found in the area surrounding the displaying site. Therefore, stocking rates seem to be more effective in describing the habitat of the species.

Lastly, we comment on the interaction between green plant availability and livestock rotation in the fields. Long-term rotation grazing frequently leads to two extreme sward types: (1) heavy grazed swards or (2) ungrazed swards with dominance of dry and tall Gramineae vegetation. Both scenarios are expected to result in lower availability of green plant cover (N. Faria, pers.obs). The importance of green plants for little bustards was already described in other studies (Jiguet, 2002; Silva et al., 2007) and is probably higher during the chick rearing period, from mid-May onwards when the rise of air temperatures quickly dries the vegetation. During this period, areas with green plants become progressively scarcer, and so do hotspots of arthropods, the main food resource of chicks (Jiguet, 2002). The presence of higher levels of green vegetation can so favour the use of pastures under this type of livestock rotation, which could be particularly important since these types of pastures are theoretically less disturbed. Conversely, continuous and short-term grazed swards tend to be very homogenous, makes the detection of this relationship difficult.

Conservation Implications

The main threats to little bustard habitats in our study area are associated both with the lack of grazing and heavy grazing. Many types of grasslands are managed for summer grazing and hay production and are left ungrazed for several months, thus resulting in poor habitats due to the height

and density of grasses. On the other hand, heavy grazing compels the species to occupy sub-optimal habitats, which might negatively affect breeding performance.

Light-moderate stocking levels are not easy to adjust due to a strictly fast-profit based vision of European farming activities and the general interest of landowners and livestock breeders. Yet, within the EU, the ongoing reforms of the CAP are putting a greater emphasis on the need of a sustainable and multifunctional agriculture. In order to achieve these targets, agri-environmental schemes were implemented after the 1992 CAP reforms (Regulation 2078/92), aiming to encourage farmers to apply environmentally sound practices. Nonetheless, some of them did not return the expected results for species and habitats (e.g. Kleijn et al., 2001; Zechmeister et al., 2003; but see Concepcion et al., 2008). Prescribed stocking rates are expected to indirectly optimise the key features of habitats (e.g. vegetation parameters and insect abundance/diversity). When complemented by other habitat management measures (cutting, legume sowing), which are potentially simpler and cheaper to implement, such practices may create larger areas with adequate habitats for the little bustard. We recommend that management for livestock grazing should start before the breeding season, preferably on February (or earlier). Stocking rates around 0.2-0.6 LU/ha can enable an effective management ofhabitats provided that: (1) this interval reflects the preferences of both males and females; (2) meteorological characteristics of each year and the specific soil properties of our study area are taken into account. Thus, in wetter years and/or on best quality soils stocking rates can be closer to 0.6 LU/ha/day, while in drought years and/or on poor soils they should be closer to 0.2 LU/ha/day. It

must be stressed that our study area is relatively marginal with respect to the Iberian distribution of dry grassland habitats, thus shows some environmental peculiarities (e.g. in the availability of ground moisture). Therefore, the implementation of the suggested stocking rates in other regions should consider the need for specific adjustments to local environmental conditions (e.g. annual rainfall, temperatures and soil properties).

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5. EXPLORING NEST DESTRUCTION AND BIRD MORTALITY IN MOWN MEDITERRANEAN DRY GRASSLANDS: AN INCREASING THREAT TO GRASSLAND BIRD CONSERVATION

ABSTRACT

In recent years, haymaking has extended to Iberian Mediterranean dry grasslands potentially impacting on grassland bird ecology. We evaluated the impact of haymaking on a dry grassland bird community of South Portugal. Our main goals were: (1) to investigate the exposure of different species to haymaking; (2) to investigate potential removal of nests or dead birds by haymaking machinery using the ratio (REC) between the expected number of records and the number of records collected; (3) to link clutch destruction and bird mortality with haymaking management practices. Mown fields were surveyed for signs of breeding and birds censused prior to mowing. Linear and mixed models were computed linking the REC with haymaking machinery and sward properties. GLMs and model averaging were used to obtain models linking clutch destruction, bird mortality and mowing management variables. Only 4% of records evidenced successful nesting attempts (N=177). REC evaluation suggested high nest or dead bird removal by the machinery, particularly in fields with lower vegetation biomass prior to cutting, presenting stubbles shorter than 8 cm and where sickle bar mowers were used. Higher probabilities of mortality events were found in fields mown earlier (but not in all years) and raked with one-rotor rotary rakes. Delayed haymaking, silage production in temporary crops, leaving taller stubbles and the development of new technological solutions for haymaking are discussed as management alternatives.

KEYWORDS

Clutch destruction, hay, haymaking machinery, spontaneous grasslands, mowing, haying.

INTRODUCTION

The use of grasslands for hay production is a common and ancient agricultural practice in Europe. In recent years haymaking has extended to Iberian Mediterranean dry grasslands (particularly those of southwest Iberia). . The abandonment of mixed cropping systems of cereal grain and sheep raising for beef-cattle production and the intensification of beef farms is associated in the Évora region (and other parts of south-western Iberia), with an increase in mown surface in order to ensure the demands of plant biomass for cattle. There are no official statistics available on the surface mown yearly but in south Portugal (Alentejo and Algarve regions) between 1989 and 2013, bovine numbers experienced a 107% increase (INE, 2014a). Also, the surface of the main crops used for haymaking (forage oats, grass-legume crops or pure legume crops) increased 34% between 1989 and 2009. In southwest Spain (Extremadura and Andalucía regions), between 1999 and 2013 bovine numbers and the surface of forage crops experienced an 11% and 65% increase, respectively (INE, 2014b; MAGRAMA, 2014).

Iberian Mediterranean environments provide, under adequate soil and hydrological conditions, moderate to high primary production for hay or silage (Carpintero *et al*., 1991; Hernández *et al*., 1994; Rodríguez *et al*., 2002; San Miguel, 2009). Here, mowing for hay occurs on average one month earlier than the harvesting of cereal crops for grain, which implies an additional machinery pass through fields (raking) and often produces shorter stubbles than harvesting for grain. As seen for temperate regions, a one-month delay in mowing for hay highly penalizes farmers, due to an important loss of grass protein content

(Nocera *et al*., 2005). Under Mediterranean climate the loss of grass protein content is expected to occur even in a smaller time window since vegetation rapidly dries as soon as high temperatures arrive in May. Also, mowing is not confined to cereal and legume forage crops or wet meadows, but it also frequently occurs on pastures or fallow land, which hold important populations of threatened or near-threatened birds at European or global level, such as the great bustard (*Otis tarda*), the little bustard (*Tetrax tetrax*) or the Montagu´s harrier (*Circus pygargus*).

In temperate areas of central Europe and North America several authors suggested a link between important declines in grassland bird populations and changes in timing and frequency of hay mowing (Green, 1997; Herkert, 1997; Grüebler *et al*., 2008). Mowing machinery and mowing timings are likely to put grassland bird population at risk by causing reproductive failure through loss of nests and eggs, chick mortality or adult mortality (Vickery *et al*., 2001; Grüebler *et al*., 2008). Most of the studies on this subject focused on bird abundance before, during and after mowing under different scenarios of mowing, aiming to propose mowing practices to suit grassland bird requirements. Nocera *et al*. (2005) and Perkins *et al*. (2013) for instance, highlighted the importance of applying agreements with individual farmers to adapt their haymaking timings to the birds' breeding cycles. Broyer (2003) focused on the importance of alternative mowing practices such as inside-out meadow mowing and the creation of uncut strips in meadows. Others simply tested scaring devices to frighten families of black-tailed godwits *Limosa limosa* and keep them off a field shortly before mowing (Kruk *et al*., 1997). However, very few studies have aimed at quantifying net losses of nests or chick and adult mortality (see for

instance, Perlut *et al*., 2006; Grüebler *et al*., 2008) and particularly at evaluating how different machinery, notably mower and rake configurations, influence these parameters (see, Humbert *et al*., 2009). Moreover, the succession of events during mowing works that ends up in a potential nest loss or mortality event is largely unknown, which could hamper the design of adequate management measures.

In southwest Iberia haymaking occurs shortly before vegetation dries, typically during May, a month where most birds are incubating or have unfledged chicks. Therefore, after a clutch/brood loss due to haymaking works, both the renesting opportunity and the productivity of renesters are expected to be low. As far as we know, this is the first study focusing on the evaluation of the impact of haymaking practices in a Mediterranean dry grassland context (Alentejo region, Portugal). Our general aim is to present a first approach on the effects of hay production on a ground nesting bird community using observations directly obtained at nesting sites after mowing. Our specific aims were: (1) to investigate the exposure of different grassland bird species to haymaking practices; (2) to investigate the removal of nests or dead birds from mown fields, using the ratio between the expected number of records and the number of records actually collected (REC) and assessing the roles of type of machinery and sward properties, as well the potential biases on the detectability of records; (3) to analyze the influence of mowing machinery configuration, type of field (grazed, ungrazed, seeded) and the timing of mowing/baling on clutch destruction and bird mortality.

MATERIAL AND METHODS

Study area

The study area is located in Évora region, Alentejo province, south Portugal (centre of the study area at 38º 32'N, 7º 53'W), in the Mesomediterranean biogeographic region (Rivas-Martinez *et al*., 2004). Climate is mostly dry, although wetter at North and West quadrants. Average temperatures vary from 9.6ºC in winter to 24.1ºC in summer and the annual rainfall rounds 586mm (1981-2010 period; IPMA, 2014). This area comprises a mosaic landscape dominated by holm oak forested areas 'montados' and grasslands. Soils are mostly acidic and with low-average fertility (unpublished data). Most important land use types consist of extensive livestock grazing (mostly cattle) and cereal, leguminous or mixed crops for hay production. Cereal crops for grain are nowadays less common due to recent conversion of farms for beef-cattle production. Irrigated pastures are also rather common in this region, although marginal in surface comparatively to dry grasslands.

Sample fields were distributed in 9 farms, all larger than 500 ha and selected for this study based on the pasture/crop ratio. Within these farms, we sampled most of the hayed fields, giving preference to the fields that were previously randomly selected for bird census (see field methodology section). Mean field size in the study area is around 62 hectares.

Haymaking is usually accomplished in four stages: (1) mowing to cut the vegetation, (2) raking to gather the vegetation in lines, (3) baling to compact the vegetation into bales and (4) bale collection by a stacker and truck. In wet springs and in early mown fields it may be necessary to let the vegetation dry

for a few days after mowing and before raking. As mentioned above, there are no official haymaking statistics for the region of Évora and therefore the only data available refer to the fields monitored by our team during these three years in a larger study. In 2012 mowing started on May 16th, 10 out of 50 fields controlled presented tall and dense vegetation suitable for haymaking, 3 of which (30%) were partially or fully mown. In 2013 mowing started on May 3rd, 17 out of 50 fields controlled presented tall and dense vegetation suitable for haymaking, 12 of which (71%) were partially or fully mown. In 2014 mowing started on May 7th, 23 out of 52 fields controlled presented tall and dense vegetation suitable for haymaking, 15 of which (65%) were partially or fully mown (the adequacy of vegetation for haymaking was based on the vegetation structure measured each year in the last fortnights of April and May but see field methodology section for further details).

The study area is partly included in the Special Protection Area for birds of Évora. It holds important populations of protected grassland birds species such as the little and great bustards, Montagu's harrier, black-bellied sandgrouse (*Pterocles orientalis*) and the calandra lark (*Melanocorypha calandra*). No special regulation on haymaking is applied inside the Special Protection Area.

Field methodology

Mown fields for hay were surveyed during the months of May and June using 4x4 vehicle transects (the distance between transect lines was 10 meter; fields mown for silage production were not included here). Vehicle transects were chosen instead of foot transects because the speed of progression in

transects is higher and the number of working hours per day can double, allowing to cover a larger area and a larger number of fields, despite the fact that detectability of records from foot transects is theoretically higher.

The surface covered by transects was 158 ha in 2012 (7 fields), 148 ha in 2013 (15 fields) and 199 ha in 2014 (19 fields). The mean surface covered by field was 12.30±8.55 ha. These 41 fields were mostly large fields (only three fields have less than 20 ha) and were located within a polygon of ca. 23000 ha. The surveyed area in each field was dependent on field size and on the area mown in each field, ranging from 5-100% of fieldsize (41% of fields were only partly mown at the end of the hay season). Transects were carried out at low speed (ca. 5 km/h) after fields had been raked, using two observers searching in both sides and front of the vehicle for nests, eggs, feathers, dead birds, fledging/walking juveniles or adult birds carrying food or suspect of breeding. Following the detection of one of these signs of breeding we stopped the vehicle and intensively searched the grass on foot within a 10 meter radius from the point of detection, aiming to identify the status of the record: destroyed/active clutch, dead/living juveniles, dead adults or unknown. Feathers, eggs and for some species nests were used to identify the grassland species involved. Adult mortality was confirmed if body parts of individuals or cut flight feathers were found (see Fig. 1). Records with evidences of predation such as nests with eggs partly consumed or partly consumed birds, and nests evidencing abandonment prior to mowing (i.e. constructed with old materials, easily shattered) were not considered (these were about 5% of all observations). Also, aiming to evaluate potential effects of machinery in the plucking of nests we classified the nests found in plucked or unplucked.

Records were assigned to two classes of vegetation (stubble) height: less than 8 cm (short stubbles) and 8 cm or more (medium-tall stubbles; this information is only available for 2013 and 2014). Three types of land use for hay production were considered: cereal-based crops, ungrazed pastures during the year of haymaking and pastures grazed during the year of haymaking. Fields seeded with grasses such as raygrass, alfalfa or clover are quite rare in Évora region and thus were not considered in our sample. The vegetation structure was measured after bird counts, in the same day or at most 2 days later. Biomass samples were collected in May, in two random replicates, separated by 200 and within a square of 50 x 50 cm, using a portable cutter. In the same day, samples were transported and dried in laboratory, and later weighted using a precision balance. With exception of stubble height (measured at the location of each record), all independent variables were collected at field level and are presented in detail in Table 1.

Also, we conducted grassland bird censuses through point counts prior to mowing in order to assess potential removal of nests or dead birds by haymaking machinery. Census results were used to calculate the expected number of records (RE) in the surveyed area of each mown field, defined as the number of territories per hectare multiplied by the number of hectares surveyed at each mown field. A radius of 250 meter around the point count station and a count period of 15 minutes were assumed, recording the location and number of individuals of each species displaying clear territorial or nesting behaviour and adjusting if necessary the geographical location of territories (this procedure is particularly important in high density areas were birds spend most of their time chasing each other). The counting buffer was mostly coincident with the

surveyed area of mown fields, so we assumed that bird territory densities found at point counts reflect the expected number of records at the surveyed mown fields. Bird counts were made in the first three and a half hours after sunrise or in the last two and a half hours before sunset, in the last fortnight of April and repeated in the last fortnight of May. However, since some fields were already mown before May counts we only considered April data for the analyses. In order to obtain homogenous sampling areas, counts were only made in fields with enough size to fit the whole buffer. Due to this limitation, combined with some shifts in the fields that were actually mown some days later, bird territory estimates (and thus the RE) were available only for 29 of the 41 surveyed fields over the three years of sampling.

Data analyses

Data analyses were accomplished in four steps. First, we calculated for the three years of study cumulative descriptive statistics on the exposure of different grassland bird species to haymaking in terms of number of records per species and status of the record: clutch destroyed/active, dead/living juveniles, dead adults or unknown.

Fig. 1 - Cut flight feathers of passerine species (top), Montagu's harrier (center) and quail (bottom) used to identify mortality events in mown fields.

Table 1 - Variables used to describe haymaking management influence on ground nesting grassland birds.

Variable	Description
Year	Factor variable indicating the type year where field works took place.
VegCov	Percent of cover prior to mowing. Estimated visually at field within a 50cmx50cm square, using 18 sampling replicates disposed around each point count station.
VegBio	Biomass in grams of dry vegetation in a square of 50x50 cm (prior to mowing). Calculated from 2 biomass replicates 100m distant from point count stations.
HayT	Factor variable indicating the type of hay. Three types were defined: CBC - Cereal based crops; PU - Ungrazed pasture during the year of mowing; PG - Grazed pasture during the year of mowing.
MowVegH	Vegetation height of stubble at each record. Two classes were defined: <8cm or ≥8cm.
DMow	Date of mowing.
DBa-Mo	Difference in days between the date of baling and the date of mowing.
MowT	Factor variable indicating the type of mower: SB - Sickle bar; RD – Rotary discs; BDB – Both rotary discs and sickle bar types.
Mow2S	Factor variable indicating the position of cutting: OS – Just one side of the mower, lateral or frontal; BS – Lateral and frontal mowing.
NMow	Total number of mowers: OM – one mower; TM – Two or more mowers
RakeT	Factor variable indicating the type of rake: WR - Wheel rake; R1 – Rotary rake with one rotor; R2 – Rotary rake with two rotors.

Second, using the ratio between the expected number of records (RE) and the number of records actually collected (RC) we assessed the removal of nests or dead birds by haymaking machinery and potential biases on detectability of records. To avoid numerical problems in the fields where no records were found, this ratio (hereafter REC) was used in the form "REC=(RE+1)/(RC+1)". The differences in the mean number of records expected *vs.* collected for each species and bird groups were tested using Student´s t-tests. Then, using pooled data for all species, linear models were computed to test for relationships between the REC and the type of mower and rake used for haymaking. A similar approach was followed for sward cover and sward biomass prior to mowing (biomass estimates were log-transformed to normalize data and minimize the influence of extreme values). Potential confounding relationships between the type of land use for hay production and the explanatory variables were previously evaluated using a mixed modelling exploratory approach and the type of land use as a random factor. Model ranking and selection was performed by calculating Akaike's Information Criterion corrected for small sample size (AICc). Models with the lowest AICc and within less than 2 units of ΔAICc were selected as best models and considered similar in performance (Burnham and Anderson, 2002). Also, the relationship between the REC and the vegetation height of stubbles was investigated. Since the vegetation height of stubbles was measured at record level and the calibration of mowers was expected to have low variation for all mown fields within a farm (and thus also the height of stubbles), we accounted for potential spatial autocorrelation, using a mixed modelling approach with farm

identity as random factor (number of farms=9; mean number of mown fields per farm=3.22±1.79), considering each record as a sample unit. The residuals of the model were tested for spatial autocorrelation through Moran's I statistic (Cliff and Ord, 1981).

Third, using the same procedure of REC analyses we investigate the occurrence of nest plucking, but here given the binary nature of this variable (nest plucked or not), a binomial error and a logit link-function were assumed. The relationship between the number of plucked nests and REC was assessed using linear regression.

Finally, generalized linear models (GLM, McCullagh and Nelder, 1989) were computed to obtain explanative models linking the occurrence of (1) clutch destruction (CD), (2) clutch destruction plus juvenile mortality (CDJM), (3) bird mortality (juvenile plus adult mortality; JAM), and (4) events without information of nesting status (EWIS) and mowing management variables (see Table I for details on the full set of independent variables). We analysed the occurrence of CD, CDJM, JAM and EWIS using each record as sample unit (presence/absence data). This approach allows avoiding detectability issues due to the removal of nests and dead birds by the machinery found at field level (see results). A binomial error and a logit link-function were assumed for GLMs. We started by analysing annual variations on data using univariate GLMs to evaluate potential interactions between the independent variables and year. Then, a model averaging procedure was performed following Burnham and Anderson (2002), using in the global model (1) the machinery types (mower, rake and position of cutting) and the number of mowers as fixed factors; (2) the difference in days between mowing and baling and; (3) a fixed interaction

between the date of mowing and year. Therefore, we obtained Akaike's information criterion corrected for small sample size (AICc), and in order to compare models we calculated Akaike weights as follows:

$$w_i = \frac{\exp\left(-\frac{1}{2}\Delta_i\right)}{\sum_{1}^{R}\exp\left(-\frac{1}{2}\Delta_r\right)}, \qquad \text{where} \quad \Delta_i = AIC_i - AIC_{\min}$$

Model averaging was performed using a 95% confidence set of Akaike weights, thus obtaining the selection probability of each variable. Since even poor predictors are not expected to have selection probabilities close to zero (Burnham and Anderson, 2002), we followed the approach proposed by Whittingham *et al*. (2005) which consists in adding a single randomly generated predictor that was uncorrelated with the response variable to the existing data set of real variables. The selection probability for the randomly derived predictor (null mean and null interval) was obtained by performing 100 simulations. Model performance was evaluated using the Area Under the Curve (AUC) generated by the Receiver Operating Characteristic (ROC; Pearce and Ferrier, 2000). AUC values over 0.80 indicate good model performance (Fielding and Bell, 1997) and only models over this value were considered.

All calculations were performed using R for Windows (version 13.1.1; R Development Core Team, 2007) and the packages nlme (Pinheiro *et al.*, 2015), lme4 (Bates *et al.,* 2015), spdep (Bivand *et al.*, 2013) and MuMIn (Bartoń, 2015).

RESULTS

Exposure of grassland bird species to haymaking

Transects in mown fields returned a total of 177 records (RC) of grassland bird nesting attempts. The number of records obtained each year was strongly variable: 12 in 2012 (0.076 RC/ha), 59 in 2013 (0.40 RC/ha) and 106 in 2014 (0.53 RC/ha). Only 4% of records evidenced successful nesting attempts, 32% of which were destroyed clutches, 8% dead juveniles, 5% dead adults and 56% nests with unknown status. From this 56% of nests with unknown status, 27% were found partially or fully plucked.

The corn bunting (*Emberiza calandra*) was clearly the species with the largest number of records identified (74.42%), most of them destroyed clutches (Fig.2). Crested/Thekla larks (*Galerida* spp.) represented 8% of records (14) but contrarily to corn bunting, a larger percent of these records corresponded to dead juveniles (36%). For 36% of records (63) it was not possible to identify the passerine species (lark or corn bunting). The species with the highest proportion of nesting success was the common quail (*Coturnix coturnix*), in which four out of seven records refer to hatched eggs, hatchlings or fledglings. The adult mortality found for the little bustard (1 record) and, particularly, for the Montagu's harrier (4 records) is noteworthy since these species are quite rare within the study area.

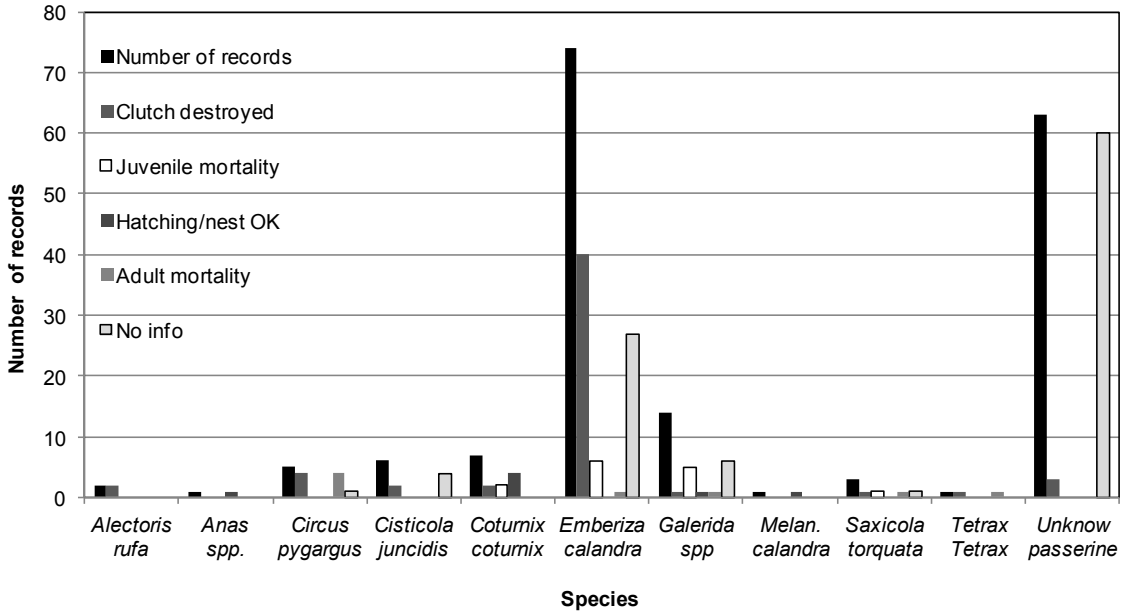

Fig. 2 - Results of transect surveys in mown fields, grouped by bird species, total number of records and observed events. The category "Hatching/nest OK" refers to the active clutches or walking juveniles (for nidifugous species).

Nest and dead bird removal: confounding factors and detectability

The inspection of REC values revealed the existence of considerable differences between the number of expected records and the number of records actually collected, in an important number of fields sampled (Fig. 3; for a best evaluation of the magnitude of this effect, the density of records per field is also provided). Passerines hold in some fields an expected number of records six times or more higher than the records actually collected (bird territory density was not significantly correlated with REC; $r=0.13$, $p=0.49$). However, these differences were only significant for the zitting cisticola (*Cisticola juncidis*) and the corn bunting, (Fig. 4). We found that REC was significantly higher in fields with lower vegetation biomass prior to mowing ($p<0.05$, $F=4.71$, $df=23$, $R^2=0.17$). No differences were found concerning the percent of cover prior to

mowing. The model including both variables returned also non significant results. Adding the type of land use for hay production as random factor did not significantly improve the models either.

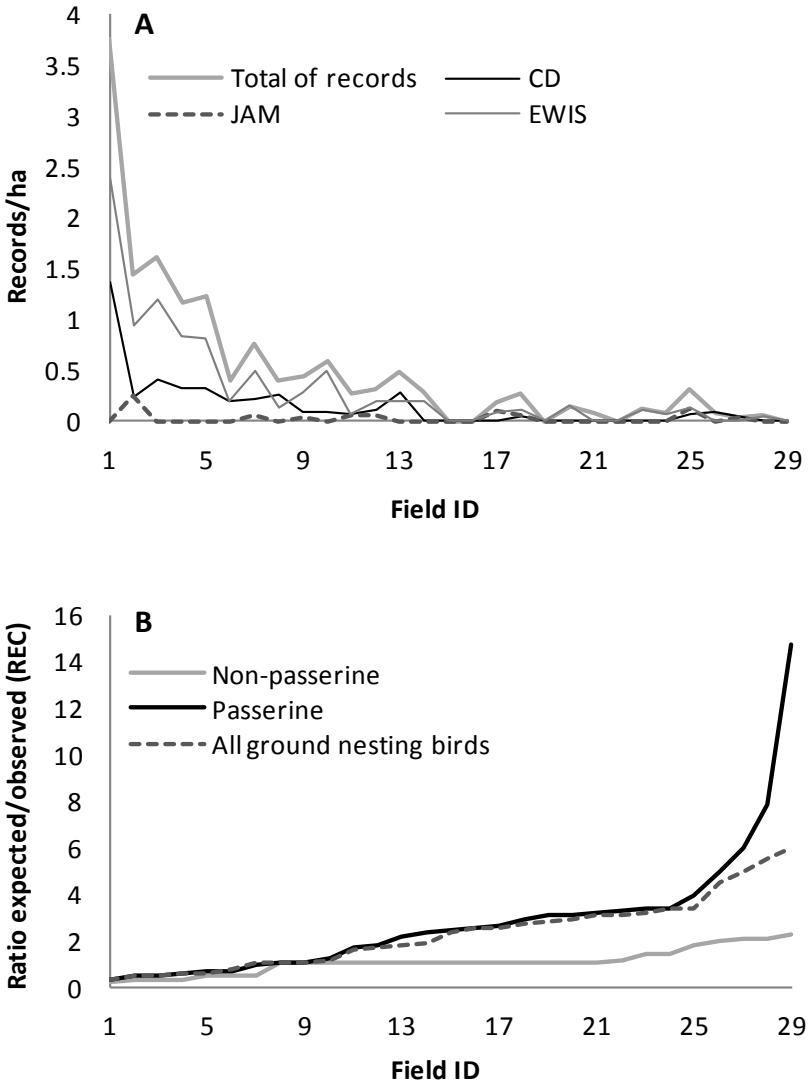

Fig. 3 - Comparative results by field of (A) nest density for different record fates (CD – Clutch destroyed, JAM – Juvenile and adult mortality, EWIS - Events without information of nesting status) and (B) REC for passerine species, non-passerine species and all ground nesting grassland birds.

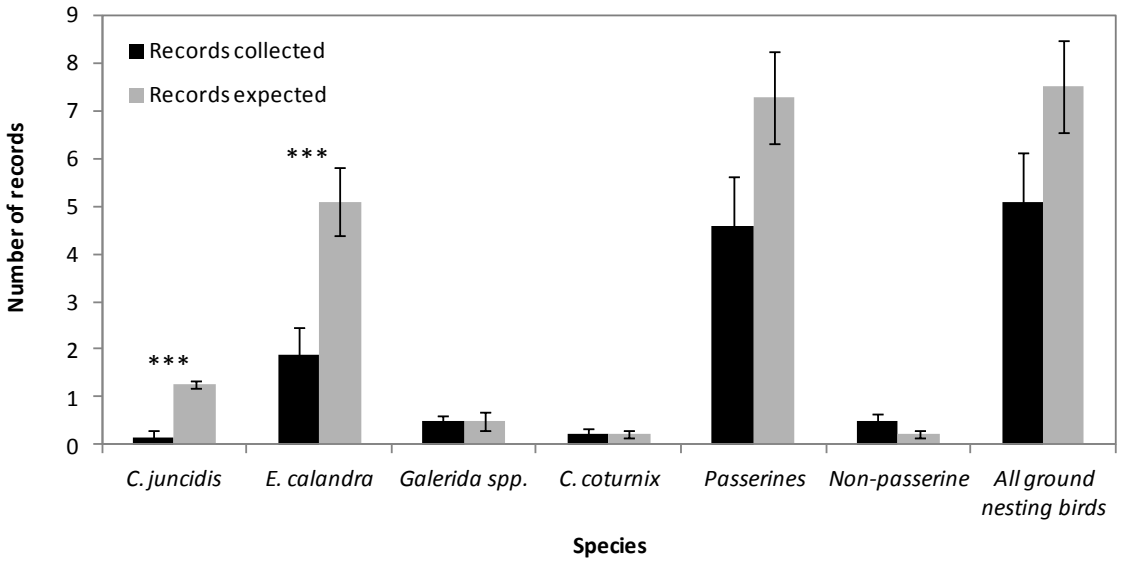

Fig. 4 - Comparison between records of breeding territories observed during transects in mown fields and the values expected from point counts. Standard errors and significant differences for the means (Student´s t-tests) are presented.

REC was related to the type of mowing machinery. The models using mower and rake type as explanatory variables indicate that higher REC values occur in fields where sickle bar mowers and one-rotor rotary rakes were used (Table 2). Opposite results were found for disc mowers and wheel rakes. Adding the type of hay as random factor did not significantly improve the machinery models The calibration of mowing machinery (i.e. the distance of sickle bar or discs to the ground) also affected the REC, since the REC was significantly higher in mown fields with stubbles shorter than 8 cm ($p<0.01$, $F=9.74$, $df=83$). This pattern depends on the type of field used for hay production and is more evident in non-grazed pastures and particularly in cereal based crops. No significant spatial correlation was detected in this relationship (Moran I =0.025; Expected Moran I=-0.011; p=0.55)

Table 2 - Best GLM models for the relationship between REC, nest plucking and rake/mower type used for haymaking (∆AICc<4). The coefficients, the statistical significance for each factor and the AICc for each model are presented. See Table 1 for a description on the categories of factor variables (rake type – "fac(RakeT)" and mower type – "fac(MowT)").

Dependent variable	Model	fac(MowT)		fac(RakeT)		AICc
		MowT (BDB)	MowT (SB)	RakeT (H2)	RakeT (W)	
REC	1			-1.72**	-1.38*	107.3
	2	0.27	1.42*	-1.10	-1.90**	108.1
Nest plucking	1			-0.09	1.59***	228.1
	2	-0.29	-0.64	0.02	1.96***	229.8

REC had a strong negative relationship with the number of plucked nests ($p<0.001$, $F=20.90$, $df=27$, $R^2=0.44$). GLM analyses on the effects of haymaking machinery on nest plucking events yielded results contrasting with those of REC analyses (Table 2). No significant improvement in the models was obtained by including the type of land use for hay production as random factor. Also, we found no significant relationships between nest plucking and biomass/cover prior to mowing or stubble height.

Linking clutch destruction, bird mortality and haymaking management

We found significant annual variations for CDJM and particularly for JAM and EWIS, but not for CD (Table 3). The probability of occurrence of CDJM and JAM was significantly lower in 2014 than in 2012, but not in 2013. On the other hand, the probability of occurrence of EWIS was significantly higher in 2014 compared with 2012 and 2013.

Table 3 - Univariate GLM results for the annual variation of clutch destruction (CD), clutch destruction plus juvenile mortality (CDJM), mortality (adult plus juvenile; JAM) and events without information of nesting status (EWIS) obtained through transects in mown fields. The variable Year was used as a three-level factor ("fac").

Dependent variable	fac(Year)	β	SE	P-value
CD	Year (2013)	0.58	0.35	0.096
	Year (2012)	0.69	0.63	0.271
CDJM	Year (2013)	0.58	0.33	0.082
	Year (2012)	1.44	0.65	**0.026**
JAM	Year (2013)	0.79	0.52	0.125
	Year (2012)	2.17	0.69	**0.002**
EWIS	Year (2013)	-0.86	0.33	**0.009**
	Year (2012)	-1.32	0.65	**0.041**

Despite the annual variations found, the averaged models for CD, CDJM or EWIS revealed weak relationships with mowing variables and interactions tested and consequently poorly accurate averaged models (AUC<0.75). However, the model averaging procedure for JAM yielded different results. As revealed by the interaction between mowing date and year, the probability of mortality events is significantly higher in fields mown earlier, but not in all years (Table 4). On the other hand, one-rotor rotary rakes produce significantly higher bird mortality, at least when compared with two-rotor rotary rakes. Fields mown with more than one mower or with double mowers (lateral and frontal) are likely to produce higher levels of bird mortality. However, results indicate only moderate selection probabilities for these variables. The time elapsed between mowing and raking also returned low to moderate probabilities in the averaged models. No significant relationships and low selection probabilities were obtained for the type of land use for hay production (either as fixed or random

factor). The AUC values for the averaged model revealed rather satisfactory accuracy for our data (averaged AUC=0.87).

DISCUSSION

The results here presented suggest important losses for grassland bird populations in the Évora region due to haymaking, showing thus concordance with similar studies elsewhere (Perlut *et al*., 2006; Masse *et al*., 2008). If further nesting success existed in our sample it must be confined to the 29% of nests with no information on the nesting status and which were not plucked (nests which produced fledglings before mowing occurred, or those that were not abandoned following haymaking).

Transects on mown fields globally revealed low adult mortality for passerine species. Grüebler *et al*. (2008) estimated overall low-moderate (11.3%) female mortality due to mowing for the Whinchat (*Saxicola rubetra*) in temperate grasslands. Our results are consistent with the observations of a testing survey carried out on top of the mower (ca. 30 ha, own unpublished data). This survey indicated that a large number of adult passerines took off before mower arrival. The situation may be quite different for non-passerines, particularly for the Montagu's harrier. Our estimates on the breeding population of this species in 2013 indicate that no more than 10 breeding pairs existed in Évora region (own unpublished data). This suggests that our four mortality records for this species represent at least 20% of adult individuals of this population.

Table 4 - Summary results for the averaged GLM model on grassland bird mortality in mown fields. The continuous variables and factors ("fac") included in each model, AICc and ΔAICc values, Akaike weights, model selection probabilities and model fits (AUC statistic) are provided. The models shown are within ΔAICc < 4.The null mean and null interval represent the selection probability for a randomly derived predictor (see methods section for further details). See Table 1 for a description on the categories of factor variables included in models.

Model	fac(MowT)	fac(NMow)	fac(Mow2S)	fac(RakeT)	fac(HayT)	DBa-DMo	Dmow:fac(year)	AICc	ΔAICc	Weight	AUC
1		+		+			+	113.7	0.00	0.186	0.86
2		+	+	+			+	114.7	0.98	0.114	0.85
3	+		+	+		-0.14	+	114.8	1.09	0.108	0.87
4		+		+		-0.04	+	115.1	1.39	0.093	0.85
5		+	+	+		-0.05	+	115.2	1.55	0.086	0.86
6			+	+		-0.06	+	115.7	2.00	0.068	0.85
7			+	+			+	116.1	2.42	0.055	0.83
8	+	+	+	+		-0.12	+	116.8	3.15	0.039	0.87
9	+		+	+	+	-0.24	+	117.4	3.74	0.029	0.87
10		+		+	+		+	117.5	3.84	0.027	0.87
11	+	+		+			+	117.7	3.98	0.025	0.85

	MowT (BDB)	MowT (SB)	NMow (TM)	Mow2S (BS)	RakeT (R2)	RakeT (W)	HayT (PU)	HayT (PG)		Dmow:Year(2012)	Dmow:Year(2013)	Dmow:Year(2014)	Averaged model:	0.87
Averaged β	-0.118	2.566	1.668	3.593	-4.016	-2.345	0.848	-0.078	-0.090	-0.049	-0.035	-0.194		
SE (adj.)	1.225	2.102	0.920	3.191	1.978	1.722	0.996	1.358	0.085	0.048	0.048	0.068		
P-value	0.923	0.222	0.070	0.260	**0.042**	0.173	0.395	0.954	0.292	0.303	0.468	**0.004**		
Selection probability	0.27		0.69	0.62	1.00		0.13		0.52		1.00		Null mean:0.34 Null interval:0.24-0.76	

Bird mortality in mown fields was dependent on the timing of mowing as well as on bird phenology and yearly weather conditions which is consistent with the findings of other studies in temperate regions (Perlut *et al*., 2006; Grüebler *et al*., 2008). In 2014, favourable nesting conditions effectively started in the second week of March, when two weeks with temperatures around 20ºC and no rain led to early clutches in most of the passerine assemblage. As a result, we detected several fledging juveniles in early May just before mowing took place, so that bird mortality was less probable to occur in late mown fields as revealed by our averaged model. Further support to this conclusion comes from the fact that in 2014 the percentage of records without information on nesting status was significantly higher than in 2013 or 2012, and that some of these nests held enlarged cups and large faeces. These findings suggest that, when haymaking took place, juveniles were fully grown up or at least were able to fly. On the contrary, due to severe winter drought in 2012 and persistent early spring rains in 2013, the nesting season started late and therefore, all nests could have been evenly affected over the haymaking season. Although the effects of silage have not been addressed in the present study, we suppose that silage could help in reducing grassland bird losses in these dry Mediterranean agro-ecosystems because silage field works normally occur until the end of April. In contrast to temperate areas where silage is frequently linked to agricultural intensification (Newton, 2004), in dry grassland habitats under Mediterranean climate this kind of intensification is unlikely to occur on a large scale (e.g. regional) since water availability is strongly limited. On the other hand, the crops used for silage production in Évora region are mostly the same as those used for haymaking. Therefore, only mowing dates would be changed.

Although this alternative will not eliminate passerine casualties, it might be of great help in reducing mortality of those non-passerines that have not started their clutches by the time of mowing for silage. In addition, our observations indicate that fields mown for silage may provide a few weeks later medium to short grass suitable for some grassland birds (as long as they are not put into irrigation or seeded with water demanding crops after haymaking).

As seen in other studies (Green, 1997; Grüebler *et al*., 2008; Perkins *et al*., 2013), we consider that the pattern previously described for bird mortality may also apply to clutch destruction. The confounding factors acting in mown fields are likely to affect the reliability of models, notably egg and dead bird removal by scavengers as seen in other related studies (Prosser *et al*., 2008; Guinard *et al*., 2012). What predation or scavenging cannot explain is why so few nests were found in fields where bird density was high. This is particularly true for passerine species which hold relatively small territories and therefore are not expected to show significant differences between the location of territories determined at counting buffers and the real location of the nest. Haymaking machinery is likely to be the responsible for this nest disappearance and, together with scavengers, also for some unquantifiable dead bird removal. According to local farmers the presence of dead animals inside bales is not rare (some lizards and snakes were actually seen in bales during field works). The analysis of bale contents may thus return interesting results.

Rotz and Shinners (2007) refer that disc mowers may at times cause slightly more loss of biomass than do sickle bar mowers. In fact, some farmers of our study area prefer to use sickle bar mowers arguing that they can mow closer to the ground. Sickle bar mowers can easily remove the nests placed

above ground level (such as those of the zitting cisticola) and reduce the resistance of remaining nests to being plucked during raking. This is consistent with our results since higher REC values were found in fields mown by sickle bar mowers and with short stubbles (<8 cm). On the other hand, rotary rakes with one rotor are reported by farmers as less stable than rotary rakes with two rotors, hitting the ground more frequently and potentially increasing REC and nest plucking, which is supported at least by our REC results. Rotary rakes with one rotor are also a recent rake design compared with wheel rakes; thus, the contrasting results for REC and nest plucking may be essentially a result of machinery efficiency, as supported by the negative relationship found between these two variables.

The abundance of grassland birds was considerably higher in 2014 and 2013 and this is certainly one of the explanations for the annual variation in the number of records found. However, the abundance of grassland birds by itself fails to explain the magnitude of this variation, particularly between 2012 and 2014 (the maximum variation between years in bird abundance was only 43%). This variation can be further explained by vegetation structure prior to mowing since the farms sampled and the machinery used in each farm every year were mostly the same. Dry years produce sparser swards with lower biomass, therefore reducing nest plucking resistance both during mowing and raking. Dry years have the advantage of having less mown surface, but the few areas mown can act as ecological traps for some rare species such as the great or the little bustards, which often prefer medium-tall moderately dense vegetation (Morales and Martin, 2002; Faria *et al*., 2012). Indeed, two out of eight little bustard females radio-tracked in this region by our team since 2003 nested in

fields with potential for being mown, in very dry years (one of these females lost her brood due to haymaking works).

Conclusions

A systematic planning where the most valuable areas for grassland birds are looked after and a contract with specific management prescriptions, including commitments such as delayed mowing or uncut refuges, should be established between the farmers and the environmental authorities, while the remaining areas can be used, for instance, for hay (to be mown on optimal dates) or silage production using temporary crops. Calibrating mowing machinery to produce taller stubbles may be another interesting management practice to increase bird nesting success in mown fields. However, this measure introduces a potential conflict with farmers interests since leaving taller stubbles implies a biomass loss, notably of smaller highly protein-rich legumes in spontaneous grasslands. Also, as explained in the methods section, haymaking implies the use of four types of processes (mowing, raking, baling and bale collection) and it is possible that at some point after mowing, nest destruction or mortality will occur. Unless May is unusually rainy in southwest Iberia, haymaking can be scheduled in order to rake right after mowing. Therefore, the development of machinery enabling simultaneously mowing and gathering hay in lines, avoiding the use of rakes as happens with cereal harvesters, may be an important complementary measure to reduce bird casualties.

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6. GENERAL DISCUSSION

6.1. The little bustard as an indicator species for managing dry grasslands

The results highlighted in the previous chapters provide evidence that the little bustard is a good model species to investigate the factors influencing dry grassland bird habitat use in the Iberian Peninsula. The importance of arthropods, notably Acrididae and Formicidae, was recognized as well for this species in other countries (Jiguet 2002), but also for other dry grassland species such as the great bustard (Rocha et al. 2005, Lane et al. 1999), the lesser kestrel (Rodriguez et al. 2010), the Montagu´s harrier (Ribeiro et al. 2006), the Southern grey shrike (Hodar 2006) or the corn bunting (Brickle et al. 2000). Similarly, the importance of legume species was also highlighted for other species Iberian steppe birds, such as the great bustard (Pescador and Peris 1999, Bravo 2014) or the two sandgrouse species (Suarez et al. 1999).

Moreover, based on the 385 fields sampled over the course of this thesis (2012-2015), a positive linear relationship between the abundance of territorial males and total bird species richness was found in Évora region (Fig. 1). This positive relationship is more evident in May or in dry years, when the little bustard is more abundant. The linear regression model representing this positive relationship can be expressed as:

*Species richness ~ LB*** + Month* + Year****

Where LB represents little bustard male abundance and asterisks indicate the different levels of each variable's significance (*p<0.05, ***p<0.001; R^2=0.18; n=385).

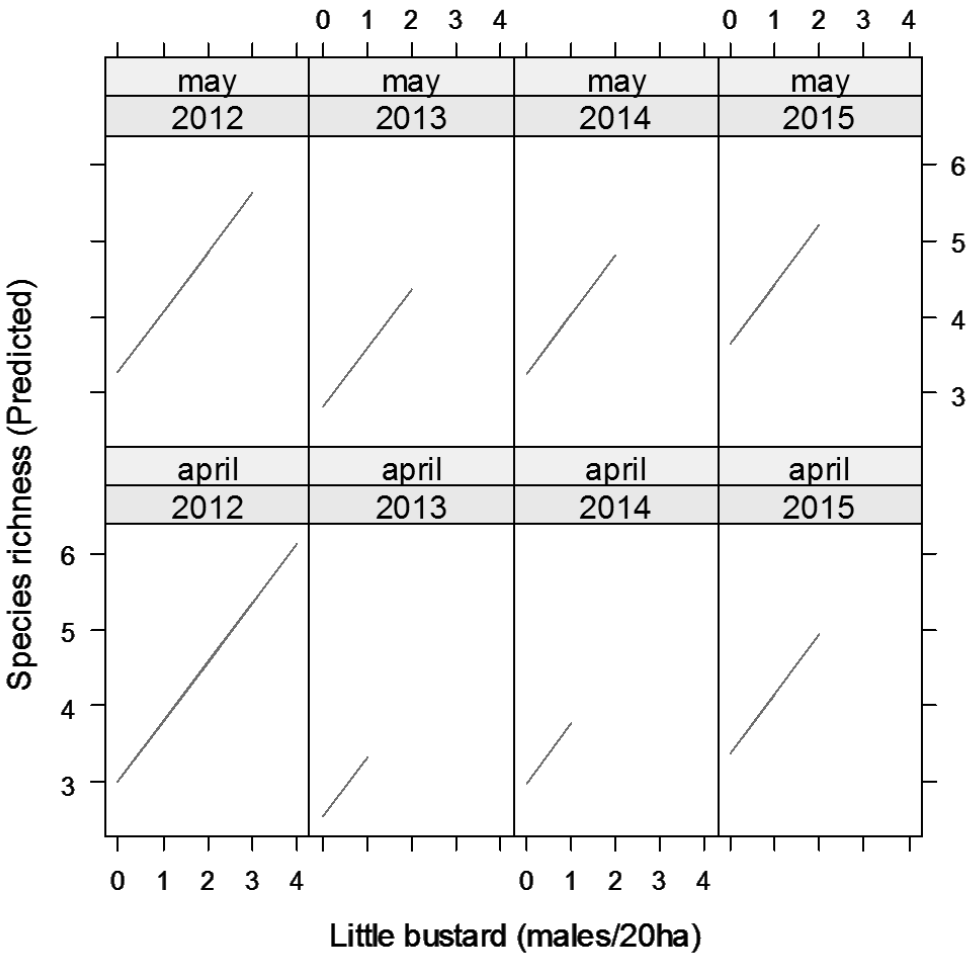

Fig. 1 - Relationship between the abundance of little bustard territorial males and bird species richness in Évora region, between 2012 and 2015 in the months of April and May.

6.2. The importance of plant composition for grassland birds: threats and solutions

The complementary role of plant and arthropod composition and abundance in Iberian pasture-dominated agricultural landscapes was investigated and their importance highlighted for the little bustard. As stated in Chapter 3, higher floristic richness and Fabaceae abundance are likely to enable higher abundance of food resources. The loss of grassland diversity in Mediterranean areas following the ongoing intensification processes caused by haying or livestock grazing may thus seriously threat the future of grassland birds and their habitats. As pointed by Huyghe et al. (2014) for the grasslands of temperate Europe, the homogenization of grasslands using plant species with commercial interest may result in an impoverishment of Iberian grasslands. Yet, in the last years, as a result of the subsidies enabled by the UE policies (that reached up to 80% of the costs of installation of grasses) the use of grass mixtures has become generalized throughout the Alentejo region. We have assisted to the replacement of typically Mediterranean pastures and species, with other (mostly leguminous) species genetically modified to adapt to edafo-climatic conditions of Southwest Iberia and/or whose production levels depend on rainfall or irrigation Porqueddu and González 2006). However, no research has been done on the long-term effects of sowing these mixtures on native vegetation communities and on diversity of dry grasslands. Furthermore, it is expected that these practices affect the seed bank, due to the strong competition inherent to these mixtures and, consequently, the strong

dominance observed in the fields (Mellis et al. 2014, Porqueddu and González 2006).

The importance of improved pastures was already demonstrated to be particularly promising for the conservation of grassland birds in other Mediterranean areas (see Wolff et al. 2001). Therefore, solutions like pasture improvement-restoration should be taken into account in management plans for grassland birds. The results of this thesis can help defining the specific composition of seed mixtures used, which is a fundamental information to improve agri-environmental schemes widely implemented throughout the European Union.

6.3. The influence of haying and grazing on grassland birds: differences between spatial scales and sexes

The different types of grazing management, notably between-field livestock rotation patterns, can influence the availability of grassland resources for grassland birds such as the availability of green plants, as demonstrated for the little bustard. Frequently, it is hard to define the boundary between overgrazing and intensive grazing. Also, these concepts cannot be separated solely on the base of stocking intensity, since a field with a given stocking rate in a given month, presenting depleted swards and signs of overgrazing may present in the following year (with similar stocking rates) a structurally diverse vegetation suitable for most grassland birds. For little bustard males in particular, intensive grazing or overgrazing may be less problematic. However, it may influence females during the incubation or in the early stage of chick

development putting in risk their breeding performance through trampling or by exposure to predators in depleted swards. In fact, the use of areas intensively grazed and low vegetation areas by broods was not rare during fieldwork, resulting from continuous removal of vegetation in fields that formerly presented suitable vegetation structure for the species. This pattern depends on the timing of grazing and of stocking rates, and can be extended to other grassland bird species. Yet, when livestock was managed under high instantaneous stocking rates (large herds in small fields) fields became depleted of vegetation (and birds) in a few days.

On the other hand, in more productive soils undergrazing leads frequently to homogenous tall/dense vegetation, presenting low grassland bird diversity (mostly those species dependent on meadow-like vegetation). Haying is associated with these tall grass habitats so that, as revealed by the results presented, species that occured in low or medium-height vegetation were affected in a lesser extent. The use of grazing in late April-May can reduce the density of grasses, but hardly produces an adequate vegetation structure or generates the green plant availability required to attract birds linked to low or medium-height swards.

It must be acknowledge that, due to the complex interaction between grazing and haying in areas with known trends of haying practices, it is difficult to obtain accurate models of bird response to haying, simply because the continuous use of grazing may in the sort-medium term eliminate the habitat characteristics of a formerly hayed field. On the other hand, the expansion of haying in the dry grasslands of Alentejo region (and those of the Iberian

Peninsula in general) is a recent phenomenon, and thus identifying patterns in the response of grassland species caused by this use may be difficult.

In spite of the more detrimental short-term effects for grassland birds of haying compared to grazing, it is hard to perceive how grazing (or other management alternatives) can provide the landscape heterogeneity patterns produced by haying. As stated in Chapter 2, cutting for hay production may provide an analogous effect to that of cutting for grain production, so that hay stubbles would act as a "replacement" habitat of the stubbles typical of mixed cereal-sheep systems, which had a larger extent in Alentejo Central region in the recent past.

Maintaining haying and grazing at intermediate management intensities may indirectly contribute to increase plant diversity in grasslands, as supported by our results. This effect, first defended by Grime (1973) using a trampling gradient in a European grassland, was later generalized and included in the Intermediate Disturbance Hypothesis (IDH), which assumes that such unimodal relationships between diversity and intensity, frequency or extent of various types of disturbances are widespread across ecosystems (Connell, 1978). It must also be noted that no evaluation was made within this thesis on the effects of the availability of hayed fields during winter, which according to our field observations may be valuable for some species like the little and great bustards.

While, as exposed above, inter-annual effects of haying may to contribute to overall grassland heterogeneity and produce multiple effects on the grassland bird community, the results presented in Chapters 2 and 4, showed

that short-term effects of haying strongly impact in the population ecology of grassland birds. These impacts are manifested mostly in three ways:

- Abandonment of nests and loss of clutches following the passing of haying machinery
- Juvenile and adult mortality caused by the machinery
- Induced abandonment of hayed fields and shifts to other fields in the surroundings or ending the breeding season

Finally, the research presented in this thesis acknowledges the importance of a balanced habitat management for both males and females in species with sexually dimorphic habitat selection, as seen for the little bustard. This is an important issue in the ecology of grassland birds since similar behavioural patterns are expected for other polygamous species (e.g. the great bustard; Bravo 2014). Furthermore, the results presented here support the idea that under an adequate management of grazing and haying it is possible to provide a sufficiently heterogeneous vegetation as to address the needs of both sexes.

6.4. The dry grasslands of Cabrela and Évora: relevance for grassland birds, sensitivity and paths of intensification

As stated along this thesis, the study areas of Cabrela and Évora are to some extent different in landscape patterns and therefore their importance for grassland birds can vary considerably according to yearly weather conditions and the bird guilds of interest. The Évora plains have higher potential for

accommodating species with medium-short vegetation requirements in dry years (e.g. the little bustard, the calandra lark or the short-toed lark) providing alternative habitats to the less productive ones of south Alentejo where the effects of droughts are potentially stronger. Conversely, in wetter years species dependent on tall meadow-like vegetation (e.g. the corn bunting, the zitting cisticola or the European quail) become more abundant as seen in other similar areas of Iberia (De Juana and Garcia 2005). The Cabrela area presents less variation on the abundance and richness of grassland birds, partly due to the lower stocking/haying intensities and higher inter-annual stability in the land uses, but also possibly due to the marginality and degree of isolation of westernmost grassland patches with respect to the distribution of the Iberian dry grasslands.

Nevertheless, agricultural synergies between haying and grazing management are likely to constitute a path for the intensification of dry grasslands in these regions. As seen in some cattle farms for beef production in the Évora region, haying and grazing of stubbles may be used successively from mid May onwards. In these farms, where soils often tolerate frequent sowing, large livestock numbers are stabled in the same field during the autumn-winter period and supplemented with artificial food or hay/silage from previous spring. At the same time, most of the remaining grassland surface available is cultivated with cereal (usually oats or triticale) or mixed cereal/legume improved crops, which depending on the development/productivity of the crop in late April can be used to produce hay, silage or grain. The cycle ends with the return of livestock to the fields sown with these crops right after haying, resulting in depleted fields for grassland

birds from late spring onwards. This type of management reduces landscape heterogeneity, leading to generalized either tall/dense or overgrazed vegetation before haying and depleted fields a few weeks after haying and subsequent grazing (Fig. 2).

Other farms use an analogous management system also stabling and food-supplementing livestock during the autumn winter period but leaving the remaining grasslands in fallow for haying. This management system is mostly applied in farms with low soil productivity. It usually demands a regular rotation of livestock or smaller herds and therefore is more adequate to promote the diversity of grassland bird communities. In both management systems, dry years are likely to disrupt the management cycle, forcing farmers to use direct grazing and favouring earlier and regular rotation of livestock in deficiently developed crops or in fallow fields managed for haying.

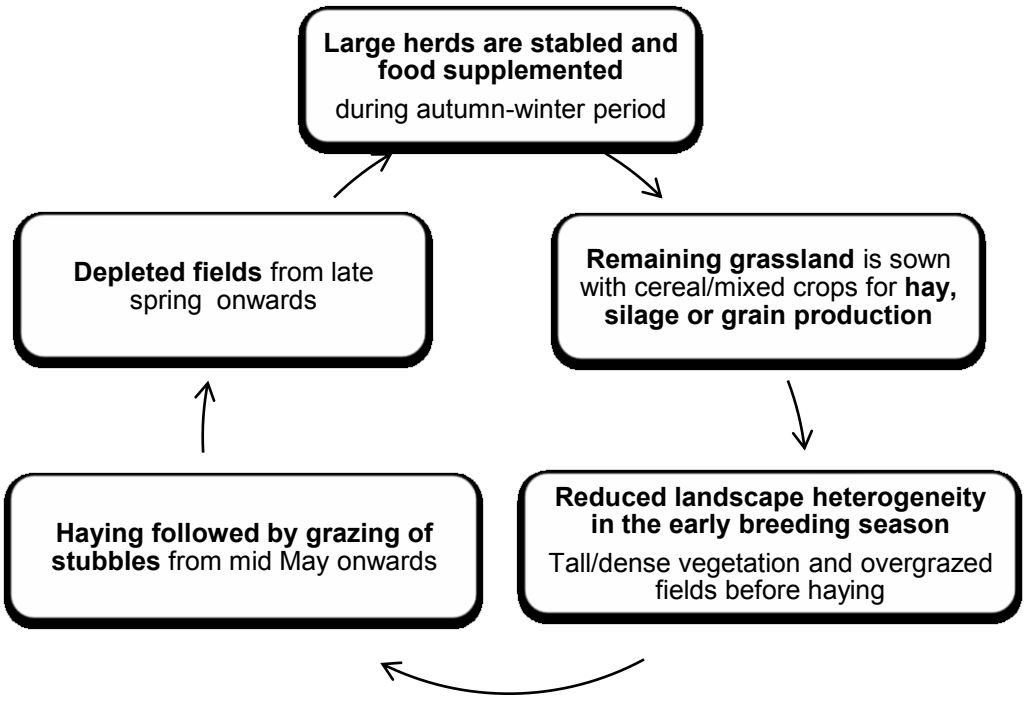

Fig. 2 - Grassland management intensification processes in intensive cattle farms of Alentejo.

7. FINAL REMARKS - RECOMMENDATIONS TO THE CONSERVATION OF DRY GRASSLAND BIRDS AND THEIR HABITATS

This work highlighted the importance of grazing and haying in the maintenance of dry grasslands in Alentejo region. The effects of these management variables were exposed according to spatial scale (landscape vs. microhabitat) and intra-specific variation (differences in selection of resources between sexes) as tool for modeling. These results revealed the usefulness of the little bustard as indicator species in dry grassland environments to track changes and ongoing intensification processes in their management.

Finally, I evaluated the relevance for the study area of studying grassland birds and their habitats, focusing on its sensitivity to changes in grassland management and on the current or expected future paths of intensification.

As conclusions, I summarise and highlight the main dry grassland management recommendations for the conservation of grassland birds in Mediterranean environments derived from this thesis. These were produced in accordance with the main conclusions of the previous chapters. A general description of their advantages, applications and added value is supplied. Also, their relationship paths with environmental variables, grassland habitats and grassland birds are presented in Fig. 1.

A. *Haying Rotation and Partial Haying* (Chapter 2)

Maintaining haying at low levels, let's say, about 20-30% of the grassland surface available in each farm, may in concordance with the results presented ensure adequate landscape heterogeneity levels for grassland birds. The decision on what fields should be included in the rotation should consider soil productivity and weather conditions of each year. This reference value should also take into account the surface used for grain production. On the other hand, partial haying may enable a balanced impact on the overall grassland species, providing refuge areas and easy food access to those birds still keeping their nests/chicks after haying works.

These measures are easy to implement at large scale involving a medium-term scheduling of fields for haying (on preference 4-5 months prior to haying).

B. *Information on plant species composition (IPSC) for grassland improvement-restoration* (Chapter 3)

The information on plant species composition requirements at little bustard breeding grounds allows going further in identifying the most favourable seed mixtures for pasture improvement-restoration. The plant species identified are typically Mediterranean species thus, they can more easily adapt to local environmental conditions (i.e. temperature and rainfall regimes, soil type and productivity) and grant an easier and more successful installation in grasslands. This information complements the already existing one based on vegetation structure requirements of grassland species, contributing to restore grasslands

in terms of plant diversity and legume species prevalence and indirectly, to improve the supply of food resources for birds (arthropods).

C. Prescribed Ecological Stocking Rates (PESR) (Chapter 4)

Prescribed ecological stocking rates allow manipulating the structural and functional diversity of vegetation (sward structure and green plants) and consequently the abundance of food resources (arthropods). The implementation of PESR should consider the need for specific adjustments to local environmental conditions (e.g. annual rainfall, temperatures and soil properties). The main advantage of PESR owns to the fact that they can be easily implemented at large scale allowing to respond to different intra-specific habitat requirements of species. Also, PESR can be easily adjusted throughout the winter and early spring to respond to abnormal weather conditions.

D. Delayed Haying (Chapter 5)

This measure acts directly on breeding success and bird mortality, providing a valuable tool in grassland management plans not only for birds but possibly for terrestrial vertebrates in general occurring in tall swards. A systematic planning should be used to introduce this measure in the most valuable areas for grassland birds used for haying through contracts established between the farmers and the environmental authorities, under which delayed haying is used in some fields, while the remaining tall swards can be used for hay on optimal dates.

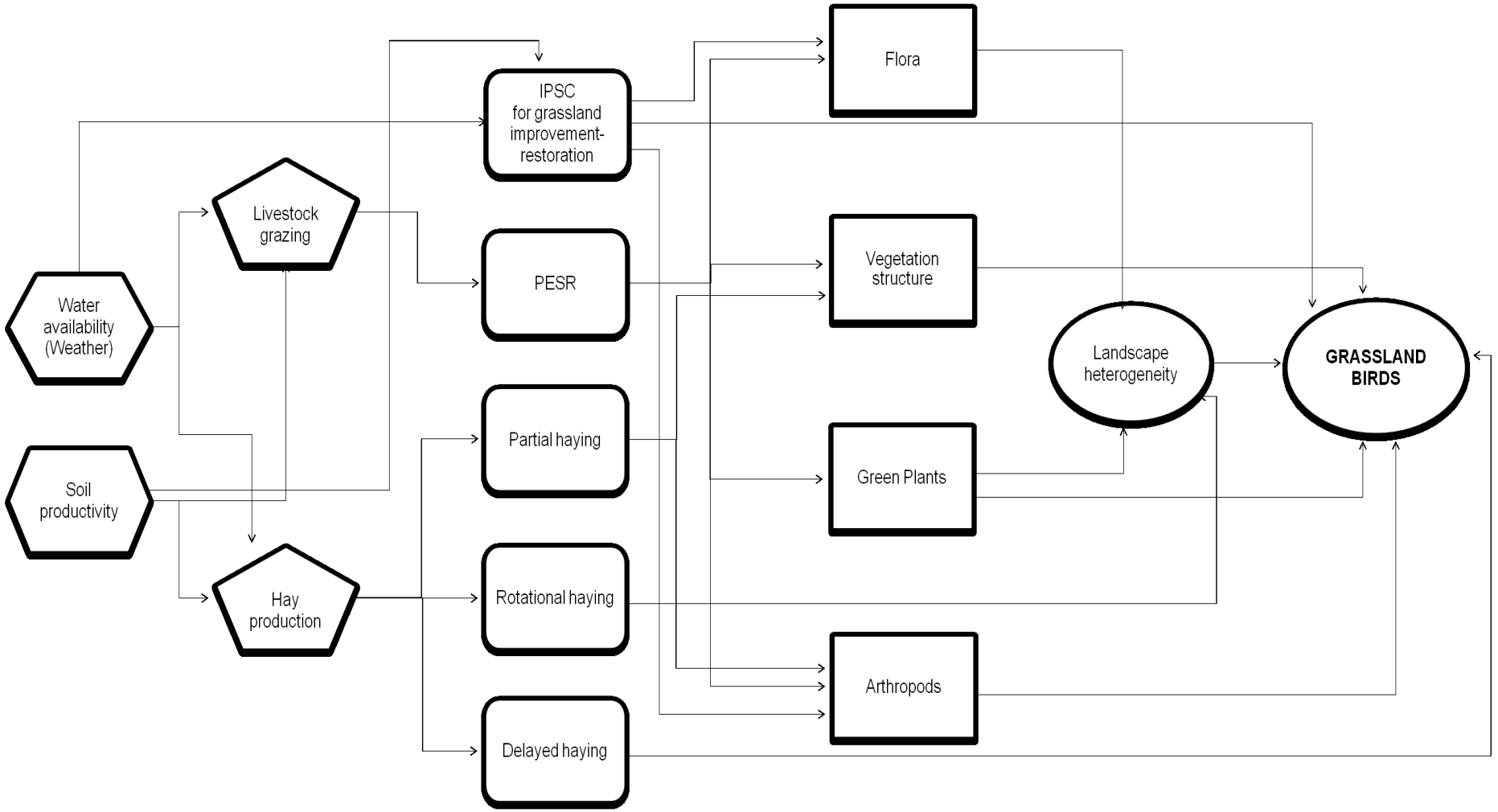

Fig. 1 - Relationships between environmental variables and the main management measures proposed for grassland birds. The symbols represent: Hexagons: abiotic factors; pentagons: management factors; rounded rectangles: proposed measures; rectangles: biotic factors).

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